ELECTRICITY

ELECTRIC MOTORS

SUPPLEMENT TO OPERATOR COURSE EXP-PR-EQ150
"ELECTRIC GENERATORS AND MOTORS"

TRAINING MANUAL
Course EXP-MN-SE140
Revision 0

ELECTRICITY

ELECTRIC MOTORS

CONTENTS

This EXP-MN-SE140 course is called "Electric Motors" and supplements electricians' course EXP-PR-EQ150 called "Electric Generators and Motors" (on the same subject)

1. OBJECTIVES 6
2. BASIC MOTOR THEORY - REVISION..7
    2.1. BASIC AC MOTOR OPERATION 7
    2.2. SINGLE PHASE MOTORS 9
        2.2.1. One or two winding motor..9
        2.2.2. Three Phase motor supplied in mono..9
            2.2.2.1. First method - with a capacitor 9
            2.2.2.2. Second method – “phases equilibrium” or “pilot motor”...........................10
3. THREE PHASE MOTOR 11
    3.1. GENERALITIES – 3 PHASE MOTOR..12
    3.2. TYPICAL CONSTRUCTION 13
    3.3. STATOR CONSTRUCTION..14
    3.4. ROTOR CONSTRUCTION 15
    3.5. ROTOR DESIGN...15
4. SQUIRREL CAGE INDUCTION MOTOR (AC)..17
    4.1. IDENTIFICATION..18
        4.1.1. Nameplate 18
        4.1.2. Name and type 18
        4.1.3. Frame designation and Motor mounting...19
        4.1.4. Protection Index “IP”..22
        4.1.5. Horsepower rating 23
        4.1.6. Ambient Temperature - Altitude..23
        4.1.7. Duty Cycle – Time Rating (Facteur de marche) 24
        4.1.8. Service factor or Service Type 25
        4.1.9. Non-balanced Voltage..30
        4.1.10. Speed rating – Slip 31
            4.1.10.1. The synchronous speed...31
            4.1.10.2. The asynchronous speed...32
        4.1.11. Example – Minimum Indications – on a nameplate 33
        4.1.12. Example – Complete Indications on a nameplate 34
    4.2. MAGNETIC AND POWER COMPONENTS...35
        4.2.1. Induction Motor...35
        4.2.2. The Stator...35
        4.2.3. Stator Windings 35
        4.2.4. Cage Rotor 36
        4.2.5. Rotor Shaft 36
        4.2.6. Bearings 36

4.2.7. Endbells....36
4.2.8. Insulated Bearings on shaft....37
4.3. INSULATION SYSTEM....37
4.3.1. Insulation Rating....37
4.3.2. Insulation Class....38
4.4. COOLING SYSTEM....39
4.4.1. Identification of cooling....40
4.4.2. Nature of Coolant....41
4.4.3. Simplified Coding – Applications....42
4.4.4. Complete Coding - Applications....43
4.4.5. Exercises....45
4.5. TERMINAL LAYOUT....47
4.5.1. Three Terminal....47
4.5.2. Four Terminal dual Voltage Motor....48
4.5.3. Six Terminal Motor....48
4.5.4. Other Connections....49
5. THE MOTOR STARTER / PROTECTION....50
5.1. STARTING CHARACTERISTICS....50
5.2. THREE PHASE MOTOR REVERSAL....52
5.2.1. Reversing the rotation direction....52
5.2.2. Reversed Windings....52
5.3. PROTECTIONS....54
5.3.1. The Motor Starter....54
5.3.2. Motor Starter Components....54
5.3.2.1. Isolation device....55
5.3.2.2. Short-circuit protection device....55
5.3.2.3. Power switching device....56
5.3.2.4. Overload protection device....56
5.3.2.5. Coordination between devices....57
5.3.2.6. Utilisation categories for AC switching....59
5.3.3. Other typical motor protections....60
5.3.3.1. Centrifugal switch....60
5.3.3.2. Windings temperature....60
5.3.3.3. Casing Heater....61
5.3.3.4. Heating with DC supply....61
5.3.3.5. Mechanical Protections....62
5.4. THE BASIC ELECTRICAL MOTOR PROTECTION....62
5.4.1. Typical curves....62
5.4.2. Protections for High Voltage and Low Voltage motors (above 75 kW)....64
5.4.2.1. General protection relay....65
5.4.2.2. Balanced and unbalanced thermal overload (code 49)....68
5.4.2.3. Unbalanced (46)....68
5.4.2.4. Overcurrent (50)....69
5.4.2.5. Short-circuits (51)....71
5.4.2.6. Earth faults (50N or 50G, 51N or 51G)....72
5.4.2.7. Start-up protections....73
5.4.2.8. Undercurrent Protection – (Pump un-priming) - (37)....75
5.4.2.9. Undervoltage (27)....75

5.4.2.10. Other protections for motors....76
5.4.2.11. Special Protection for Synchronous Motors 76
6. COMMON MOTOR STARTERS....77
6.1. DIRECT START 77
6.1.1. DOL Starter 77
6.1.2. Protection by motor-breaker....78
6.1.3. Thermal Protection with by pass at start....79
6.1.4. Starter two rotations directions 80
6.1.5. Direct start – Dahlander connection – two speed + two rotation directions 82
6.1.5.1. Motors with pole coupling (operators course)....82
6.1.5.2. Control diagram for Dahlander coupling + rotation reversing 84
6.2. STAR DELTA START 86
6.2.1. Generalities Star-Delta 86
6.2.2. Protections possibilities in Star-Delta 89
6.2.3. Schematic –typical Star-Delta 90
6.2.4. Schematic Star-Delta and two rotation direction....93
7. MOTOR TESTING....95
7.1. FAULT TYPES 95
7.2. TESTING – INSULATION RESISTANCE 97
7.3. CONTINUITY 97
8. A.C. MOTOR BREAKING SYSTEMS....98
8.1. AC PLUGGING 98
8.1.1. Plugging Power circuit....99
8.1.2. Plugging control circuit 99
8.1.3. Protections and design....101
8.1.3.1. Contactors....101
8.1.3.2. Overload / Thermal unit....101
8.1.3.3. Motors 101
8.2. D.C. INJECTION BREAKING....102
8.2.1. D.C. Injection braking principle....102
8.2.2. Operating principle of D.C. injection 102
8.2.3. Operation of D.C. injection braking....103
9. DIRECT CURRENT MOTORS 105
9.1. ELECTRICAL FAULTS 105
9.2. MECHANICAL FAULTS 109
10. MAINTENANCE OF A TYPICAL ELECTRIC MOTOR....110
10.1. RECEPTION 110
10.1.1. Identification 110
10.1.2. Storage....111
10.2. INSTALLATION RECOMMENDATIONS....113
10.2.1. Checking the insulation 113
10.2.2. Location - ventilation....114
10.2.3. Coupling 115
10.2.3.1. Preparation....115
10.2.3.2. Rotor lock 115
10.2.3.3. Balancing 116
10.2.3.4. Precautions 116
10.2.3.5. Tolerances and adjustments 117

10.2.3.6. Direct coupling to the machine 118
10.2.3.7. Direct coupling by coupling sleeve 118
10.2.3.8. Direct coupling by rigid coupling sleeve 119
10.2.3.9. Transmission by belt pulleys 119
10.2.4. Electrical guidelines 121
10.2.4.1. Maximum power of motors supplied directly from the mains (kW) 121
10.2.4.2. Limiting problems caused by motor starting 121
10.2.4.3. Earthing 122
10.2.4.4. Electric protections 123
10.2.5. Connecting to the electrical distribution network 123
10.2.5.1. Terminal box 123
10.2.5.2. Cross-sectional area of power supply cables 124
10.2.5.3. Connecting the cables 125
10.3. ROUTINE MAINTENANCE 126
10.3.1. General 126
10.3.2. Greasing 126
10.3.2.1. Life-lubricated rolling bearings 126
10.3.2.2. Rolling bearings with grease nipple 126
10.3.2.3. Rolling bearings without grease nipple 128
10.3.2.4. Rolling bearings with grease nipple 128
10.3.3. Checking the bearings 129
10.4. PREVENTIVE MAINTENANCE 130
10.5. TROUBLESHOOTING GUIDE 131
10.6. CORRECTIVE MAINTENANCE 132
10.6.1. General 132
10.6.2. PLS 160 M/MG/L and PLS 180 M/L motors 135
10.6.3. PLS 180 LG, PLS 200 M/L/LP and PLS 225 MR motors 138
10.6.4. PLS 250 and PLS 280 SC/MC/MD motors 141
10.6.5. PLS 315 motors 144
10.6.6. PLS 355 and PLS 400 motors 148
10.7. INSULATION VALUES 151
10.7.1. Insulation measurement and scheduled maintenance 151
10.7.2. Effect of climatic conditions 151
10.7.2.1. Temperature 151
10.7.2.2. Humidity level 152
10.7.3. Interpreting insulation measurements 152
10.7.3.1. Method based on the effect of the test voltage application time (Polarisation index) 152
10.7.3.2. Method based on the effect of test voltage variation (stepped measurement) 155
11. GLOSSARY 156
12. SOMMAIRE DES FIGURES 157
13. SOMMAIRE DES TABLES 160

1. OBJECTIVES

The maintenance electrician (or future maintenance electrician) has already learned a certain amount from operator's course EXP-EQ-EQ150. *That course must obviously be studied before this one.*

In the first course the electrician will have learned:

- The theory of electric motor operation
- The different types of motors (dc / synchronous / asynchronous)
- Their technologies
- How to choose a motor for an application
- The precautions to be taken when operating electric motors
- The protections on the electric circuits supplying electric motors
- The first level of maintenance for electric motors
- The faults and incidents which can arise on electric motors (and how to correct them)

At the end of this present course which is complementary to the first course, the electrician (the same electrician) must be able to carry out the following for electric motors used on the site:

- Differentiate and list the different components of a squirrel cage motor
- List the systems and cooling principles of a squirrel cage motor
- Explain the different insulation methods for the windings
- List the different electrical protection systems
- Associate, choose and determine the appropriate protection system(s) for an electric motor
- Follow a starting system control and power diagram
- Explain the measures to be taken to maintain electric motors
- Remember the useful paragraphs in this course and those in the operator's course on the same subject which you can use in your daily work.

2. BASIC MOTOR THEORY - REVISION

Already seen in the operator course EQ 150, but just to remember what was said and restart an “other” course on clear basis. For the basis of magnetism and induction phenomena’s, see also the courses EXP-PR-UT010, “Electricity” and EXP-MN-SE010, “Generalities on Electricity”

We shall insist mainly on the 3 phase AC Motor (HV and LV) as the one being mainly used and maintained on our sites

2.1. BASIC AC MOTOR OPERATION

An AC motor has two basic electrical parts: a "stator" and a "rotor" as shown in Figure.

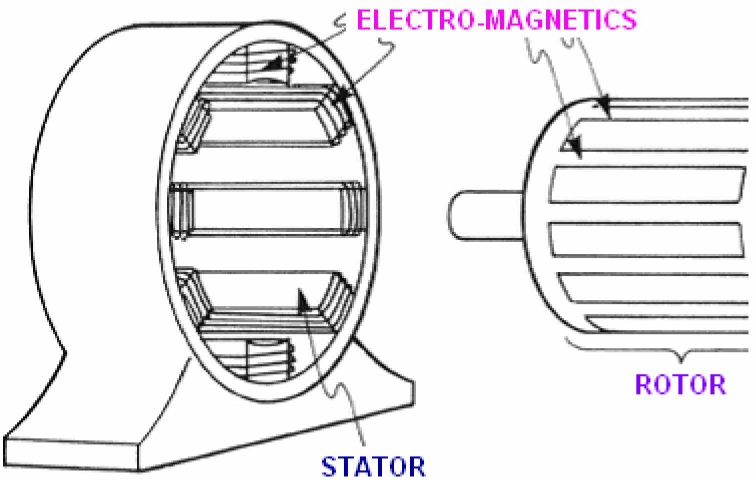


Figure 1: Basic Electrical Components of an AC Motor

The ***stator*** is in the stationary electrical component. It consists of a group of individual electro-magnets arranged in such a way that they form a hollow cylinder, with one pole of each magnet facing toward the centre of the group. The term, "stator" is derived from the word stationary.

The stator then is the stationary part of the motor.

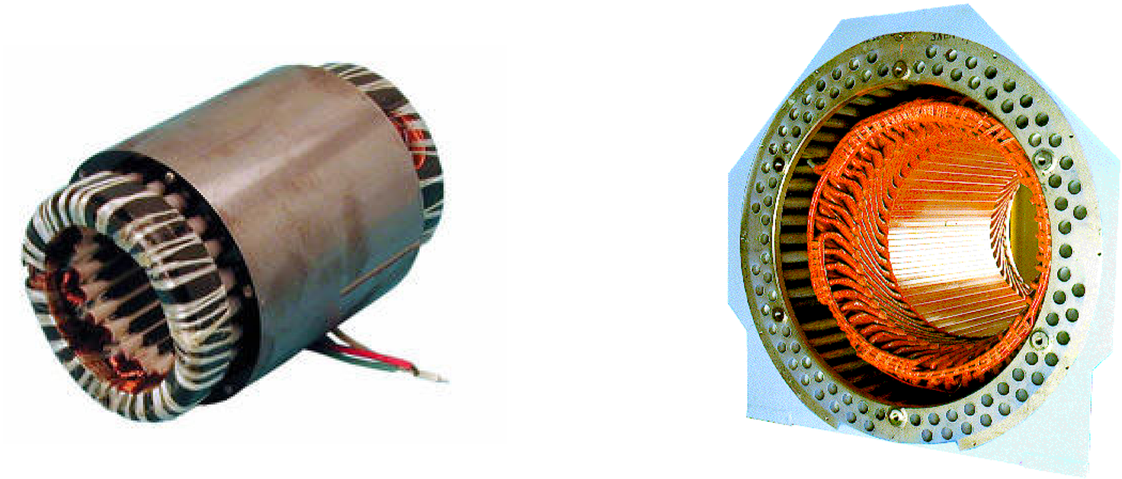


Figure 2: Stators of induction motor

The ***rotor*** is the rotating electrical component. It also consists of a group of electro-magnets arranged around a cylinder, with the poles facing toward the stator poles. The rotor, obviously, is located inside the stator and is mounted on the motor's shaft. The term "rotor" is derived from the word rotating. The rotor then is the rotating part of the motor.

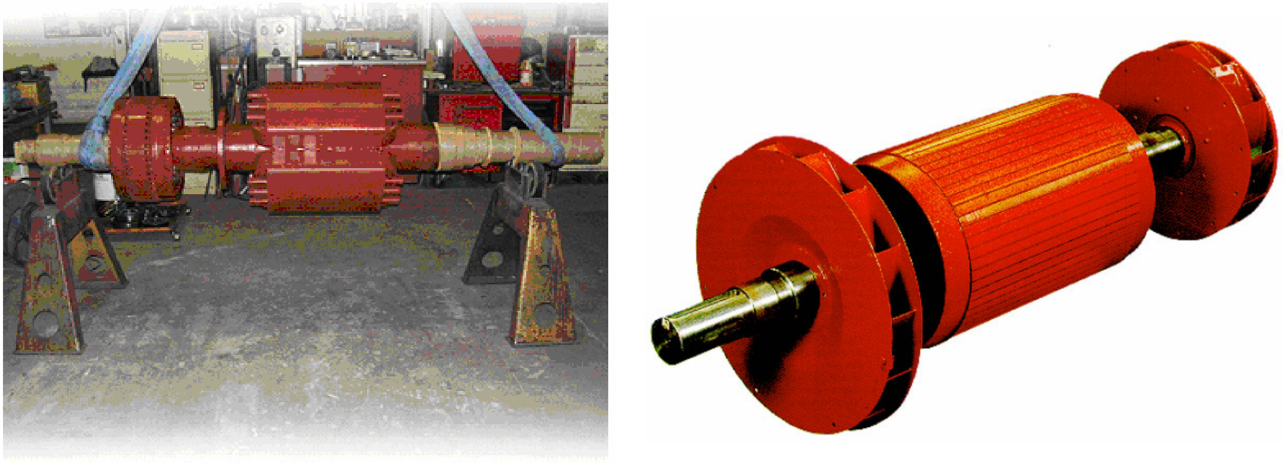
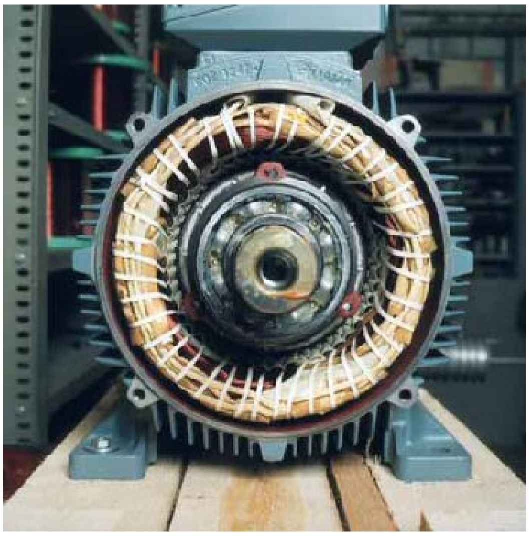


Figure 3: Rotors of induction motor



The objective of these motor components is to make the rotor rotate which in turn will rotate the motor shaft. This rotation will occur because of the magnetic phenomenon that unlike magnetic poles attract each other and like poles repel. If we progressively change the polarity of the stator poles in such a way that their combined magnetic field rotates, then the rotor will follow and rotate with the magnetic field of the stator.

Figure 4: Stator and rotor

Of course, on this last picture, it is missing one flange holding the concerned bearing here shown mounted on the shaft.

2.2. SINGLE PHASE MOTORS

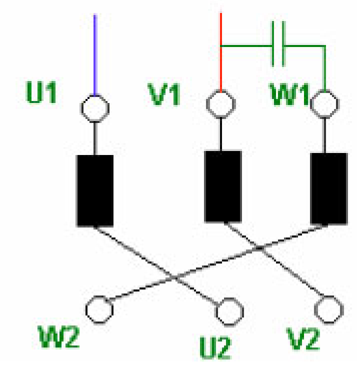
2.2.1. One or two winding motor

See Chapter 11.1 in operator course EXP-PR-EQ150.

2.2.2. Three Phase motor supplied in mono

Already in the course for operator, but let's see some complementary information.

2.2.2.1. First method - with a capacitor



Small power motors (3 Ph - less than 1kW) can be supplied with only one phase by adding one capacitance connected between one supply connector and the "non used" (third) winding terminal.

Figure 5: Connecting 3 Ph motor in mono

Rotation direction is obtained by connecting the capacitor either on one supply pole (between W1 and V1) or on the second pole (between W1 and U1)

Connection in Star or Delta on the motor terminals box is to be as per the manufacturer name-plate.

Note: power in mono is 60% compared to the one in tri.

Capacitance calculation:

It is not so obvious to calculate / determine the value (in microfarad) of the capacitor. There is no true formula, only experience and tests are required to "adapt" the correct capacitance e with the concerned motor.

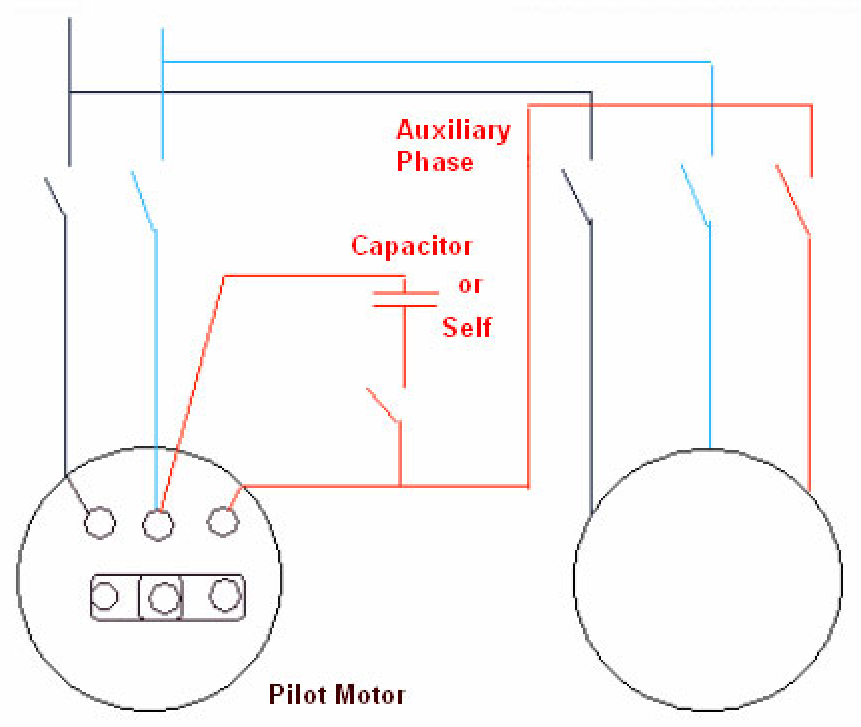
Start with a value of 8.2 microfarad per kW representing the rated power of the motor, this for a voltage supply of 220AC. This value is to be divided by 3 when the voltage is 380 / 400 VAC. When testing the motor, if the torque is not sufficient, proceed with other tests, increasing the value of the capacitor.

Caution: do not mix this 3 windings motor (like for a 3 phase) with a one phase motor with 2 windings running and starting as well with a capacitor.
See course for operator EXP-PR-EQ150, paragraph 11.1 where you can find description of all types of systems for running motors with one phase supply (including this here 3 windings type).

2.2.2.2. Second method – “phases equilibrium” or “pilot motor”

This method is convenient for one or several motors in duty, running in “parallel” with the pilot motor.

Connect the pilot motor and its slave motor (one or several) as per the diagram in this chapter



First:
Start the pilot motor, as per the method here above described.

Note that the capacitance can be replaced by an inductance, the only objective is to have a 90° phase shift either leading or lagging.

Figure 6: Pilot motor method

Then:
Once the pilot motor well on line (non-loaded), open the circuit of the capacitance (or inductance).

This system gives on the terminals of the pilot motor the potential of a third (artificial) phase. The “3 phases” then available can be used to supply one or several 3 phases motors supplied directly like from a 3 Ph network.

Finally:
In running conditions, we need at least one motor on line (not necessarily the pilot) to keep the system operating. Power of the pilot motor must equal at least the one of the more powerful duty motor; this pilot motor having to take the full starting load of the (first) duty motor.

3. THREE PHASE MOTOR

As already said above this is the one which is interesting us mostly. We do have on site “one phase” motor as well as direct current motors, but the three phase motor is the one representing the greatest percentage of utilisation.

Among the 3 phase motors, also called “asynchronous motor” used on site, different types, of course exist. The 3 main types being:

- Squirrel cage
- Wounded rotor
- Synchronous motor

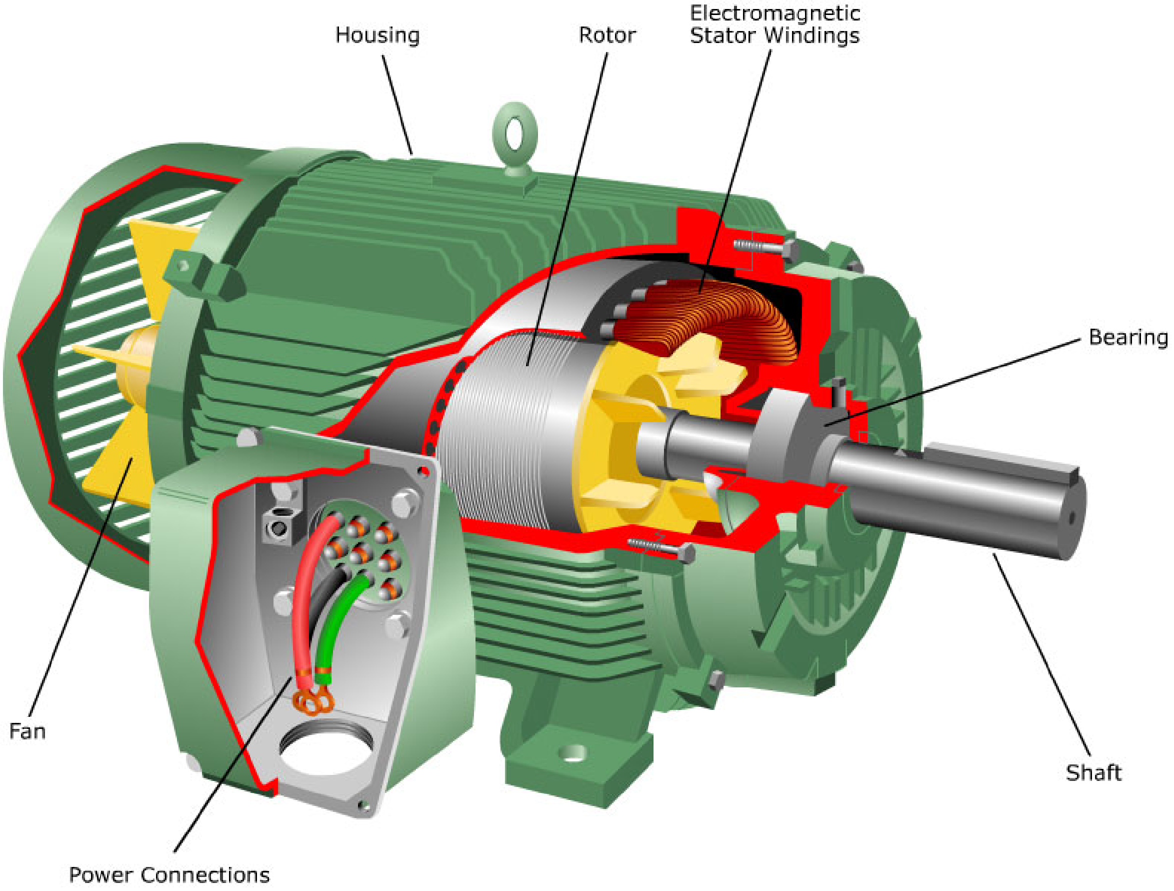


Figure 7: Typical three phase motor (squirrel cage)

The one used on site at nearly 100% is the “squirrel cage induction motor”, subject of the following chapter(s). In the past wounded rotor motors (with high starting torque) were used to “ease” the starting time (reducing peak current), but now all starting methods are on the stator windings of a “classic” squirrel cage motor, even for HV motors (up to 11 kV).

Note: the synchronous motor, also called the “synchronous machine” is either a motor or a generator having exactly the same construction technology. On the maintenance point of view, there is no difference between those two “identical” machines; consequently, see the course EXP-MN-SE060 “Electrical Power Generation” for information on this subject.

3.1. GENERALITIES – 3 PHASE MOTOR

The AC induction motor is by far the most common of all the different types of motors used in industry.

In its single and three phase forms it provides mechanical power to cope with a wide range of industrial tasks.

The AC induction motor has a number of advantages over the DC machine; its negative aspect is the consumption of reactive power used to magnetise the electromagnetic iron based body and the gap between stator and rotor

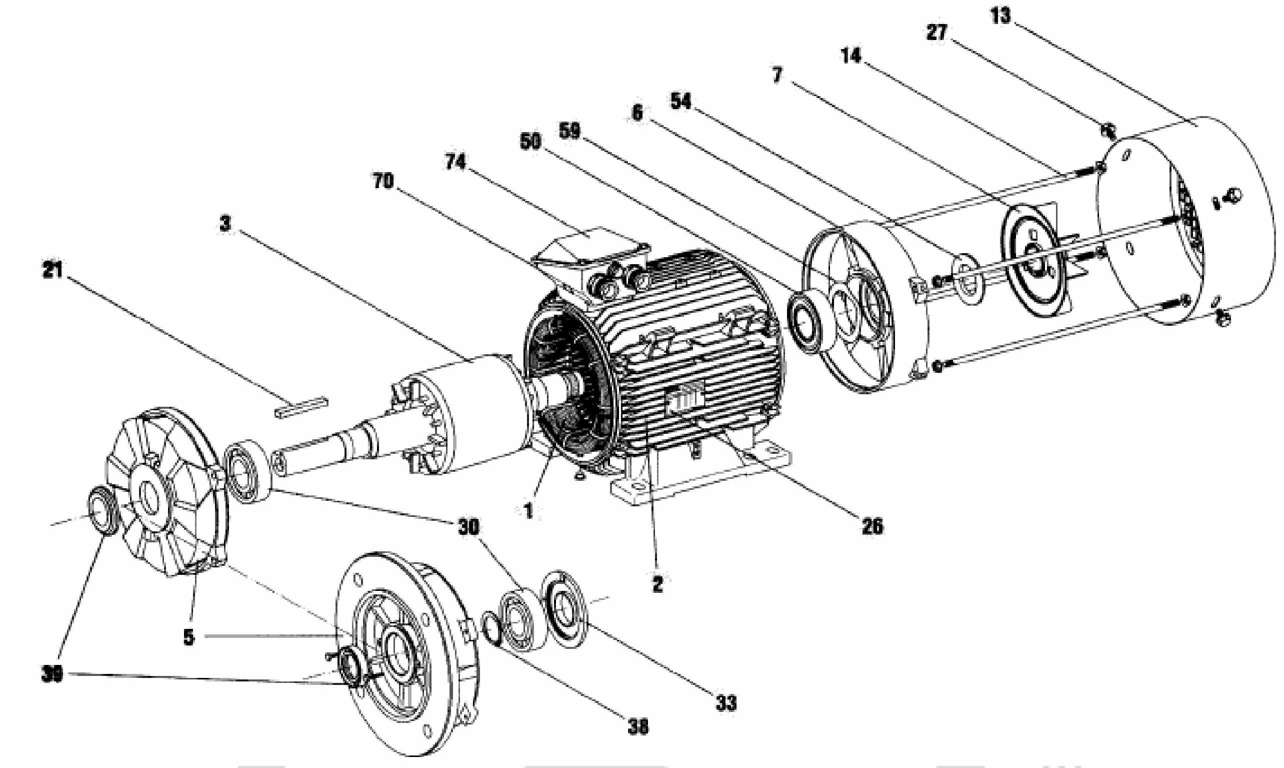
Advantages:

- AC supplies are readily available in industry
- Cheaper to manufacture / buy than DC machine
- No switch so less maintenance

Inconvenient:

- Reactive power consumed

3.2. TYPICAL CONSTRUCTION



1	Wounded rotor	27	Cover screws
2	Body	30	End bearing
3	Rotor	33	Internal cover drive end side
5	End Bell	38	Bearing circlips -end side
6	Back Bell	39	Gasket end side
7	Fan	50	Back bearing
13	Fan cover	54	Back gasket
14	Assembly rods	59	Pre-loading washer
21	Shaft pin	70	Connecting box body
26	Nameplate	74	Conecting box cover

Figure 8: Details of construction for a typical three phase motor

3.3. STATOR CONSTRUCTION

The stator is the stationary part of the motor.

- The stator is the outer body of the motor which houses the driven windings on an iron core.
- The outer casing is often finned to increase the surface area assisting cooling.
- In a single speed three phase motor design, the standard stator has three windings, while a single phase motor typically has two windings
- The stator core is made up of a stack of round pre-punched laminations pressed into a frame which may be made of aluminium or cast iron.
- The laminations are basically round with a round hole inside through which the rotor is positioned.
- The inner surface of the stator is made up of a number of deep slots or grooves right around the stator.
- It is into these slots that the windings are positioned.
- The arrangement of the windings or coils within the stator determines the number of poles that the motor has.
- A standard bar magnet has two poles, generally known as North and South. Likewise, an electromagnet also has a North and a South pole.
- As the induction motor Stator is essentially like one or more electromagnets depending on the stator windings, it also has poles in multiples of two. i.e. 2 pole, 4 pole, 6 pole etc.
- The winding configuration, slot configuration and lamination steel all have an effect on the performance of the motor.
- The voltage rating of the motor is determined by the number of turns on the stator and the power rating of the motor is determined by the losses which comprise copper loss and

3.4. ROTOR CONSTRUCTION

The rotor is the rotating part of the machine, due to its appearance, which is a cylindrical cage of copper / brass bars brazed to circular end rings or cast with them it is sometimes referred to as a "squirrel cage"

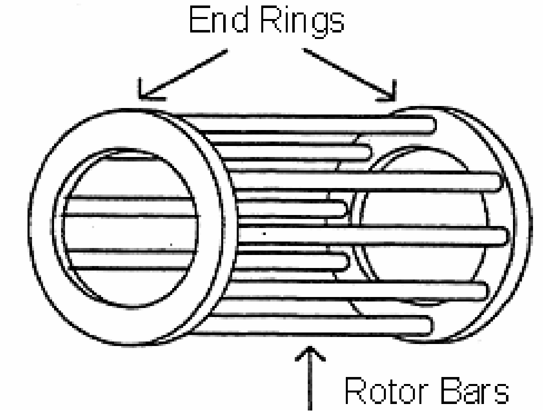
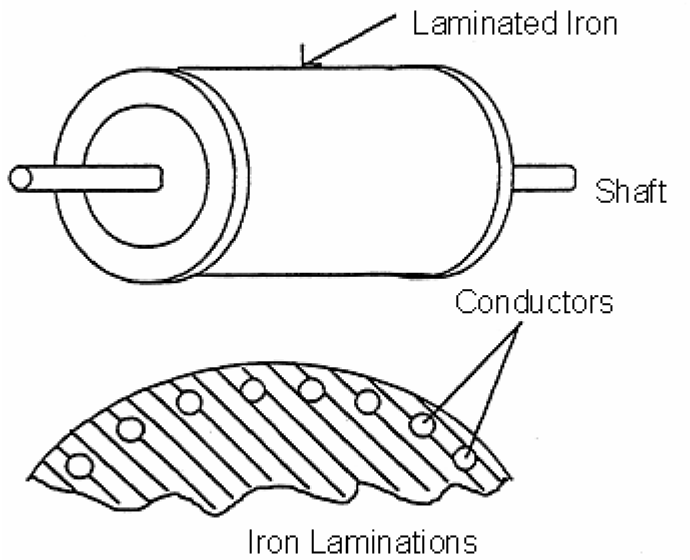


Figure 9: Typical rotor construction (squirrel cage)

The cage is completely filled with soft steel laminations. The majority of small to medium size machines have aluminium rotors cast from high purity aluminium poured round a stack of soft steel laminations which from the ferrous core of the motor. The bars are skewed so that they do not lie exactly parallel to the stator windings.



This improves the starting torque and reduces vibration when the motor is running. The rotor is mounted onto a carbon steel shaft, which may also carry a cooling fan.

The rotor is held in position between bearings housed in the motor end bells.

Figure 10: Typical rotor construction (squirrel cage and lamination)

3.5. ROTOR DESIGN

- Unlike other types of motors, the rotor of an induction motor has no electrical connections made to it.
- Torque is developed by the interaction of the magnetic fields of the rotor and stator.
- The magnetic field of the stator induces the magnetic field in the rotor.
- The Rotor comprises a cylinder made up of round laminations pressed onto the motor shaft, and a number of short-circuited windings.

- The rotor windings are made up of rotor bars passed through the rotor, from one end to the other, around the surface of the rotor.
- The bars protrude beyond the rotor and are connected together by a shorting ring at each end.
- The bars are usually made of aluminium or copper, but sometimes made of brass.
- The position relative to the surface of the rotor, shape, cross sectional area and material of the bars determine the rotor characteristics.
- Essentially, the rotor windings exhibit inductance and resistance, and these characteristics can effectively be dependent on the frequency of the current flowing in the rotor.
- A bar with a large cross sectional area will exhibit a low resistance, while a bar of a small cross sectional area will exhibit a high resistance.
- Likewise a copper bar will have a low resistance compared to a brass bar of equal proportions.
- Positioning the bar deeper into the rotor, increases the amount of iron around the bar, and consequently increases the inductance exhibited by the rotor.
- A thin bar which is inserted radialy into the rotor, with one edge near the surface of the rotor and the other edge towards the shaft, will effectively change in resistance as the frequency of the current changes.
- This is because the A.C. impedance of the outer portion of the bar is lower than the inner impedance at high frequencies lifting the effective impedance of the bar relative to the impedance of the bar at low frequencies where the impedance of both edges of the bar will be lower and almost equal. The rotor design determines the starting characteristics.

We shall see technological details of rotor on the next chapter with the squirrel cage motor, which is in fact the definition of its rotor design.

4. SQUIRREL CAGE INDUCTION MOTOR (AC)

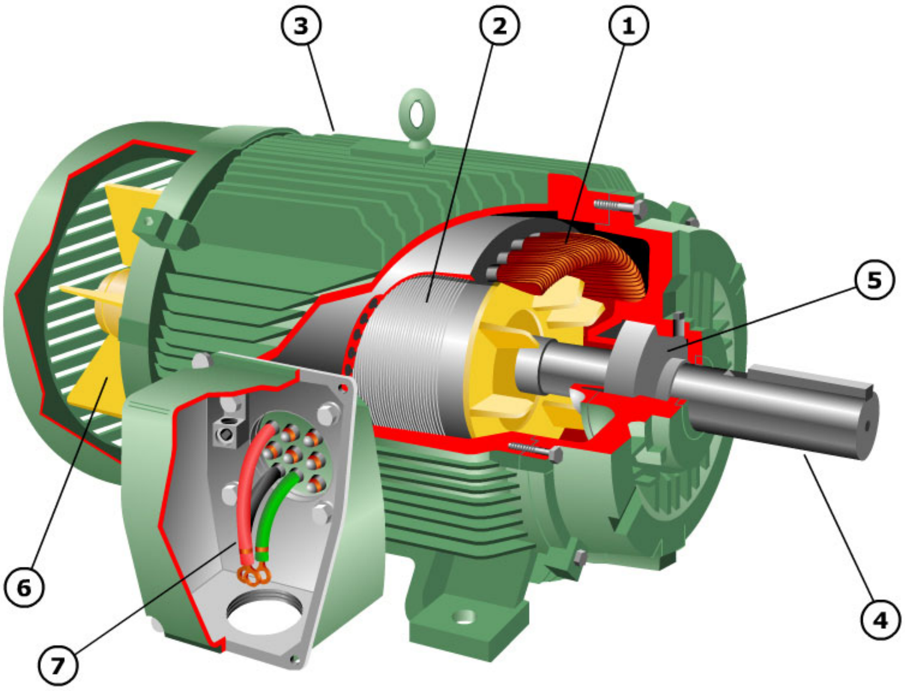


Figure 11: Typical squirrel cage motor

In chapter 3, we have exactly the same picture, the only difference is the legend replaced here by numbers.

Please, do not look above and name each part identified by a number (take it as an exercise)

The squirrel cage motor is the most widely used for the following reasons:

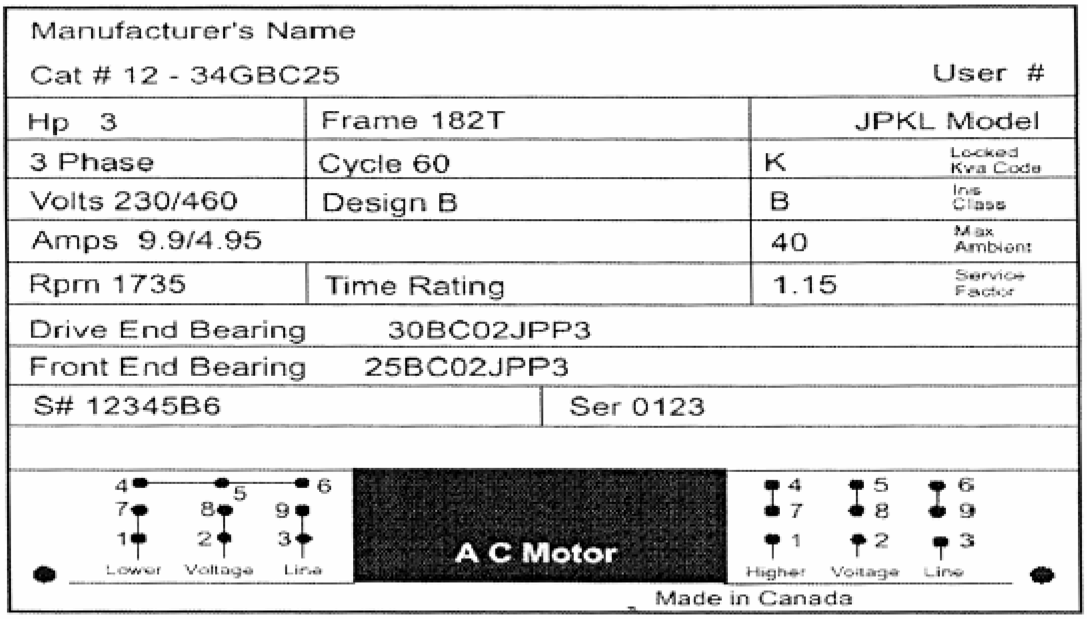
- Simple construction
- Requires less maintenance
- Rugged construction
- For any given horsepower its size is relatively small
- Speed regulation with frequency control (VFD)
- Its initial cost is relatively low
- No slip rings, no brushes – No arcing

4.1. IDENTIFICATION

4.1.1. Nameplate

In most instances, the following information will help identify a motor:

1. Frame designation (actual frame size in which the motor is built).
2. Horsepower, speed, design and enclosure.
3. Voltage, frequency and number of phases of power supply.
4. Class of insulation and time rating.
5. Application



Manufacturer's Name

Cat # 12 - 34GBC25 User #

Hp 3	Frame 182T	JPKL Model	
3 Phase	Cycle 60	K	Locked Kva Code
Volts 230/460	Design B	B	Ins Class
Amps 9.9/4.95		40	Max Ambient
Rpm 1735	Time Rating	1.15	Service Factor

Drive End Bearing 30BC02JPP3

Front End Bearing 25BC02JPP3

S# 12345B6 Ser 0123

Made in Canada

Figure 12: Typical Motor Nameplate

4.1.2. Name and type

The nameplate would include such information (taking this as general information for all types of motors) as AC induction motor, DC motor, and AC synchronous motor

This information may be encoded in the motor model or identification number

Voltage, FLC, RPM, # phase, kVA code, HP, Frequency, Service Factor, Frame, Insulation class, Duty classification

4.1.3. Frame designation and Motor mounting

- For information on frame dimensions
- Distance from the base to centre of shaft and base mounting hole dimensions
- NEMA standards are given by the code designation for the environmental conditions the motor would operate under

Motor has to be fitted and aligned with the machine to power. It is therefore necessary to specify

- its type of fixation (legs, flanges – or both),
- its position in duty,
- position of fan,
- position of terminal box
- Type of coupling, dimension of shaft (defining as well the type of bearings)
- …/…

Options are also available:

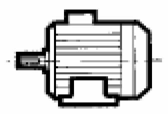
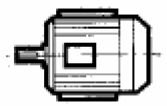
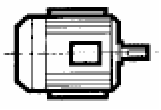
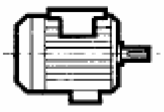
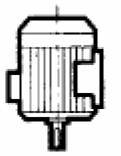
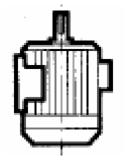
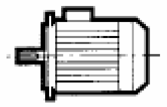
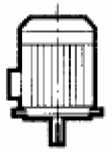
- Ventilation filter
- Speed generator (dynamo tachymétrique)
- Mechanical brake
- Speed switch
- …/…

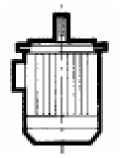
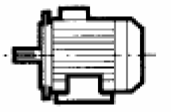
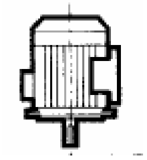
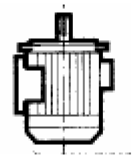
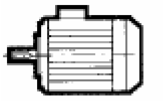
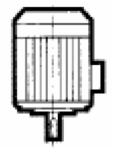
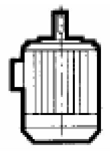
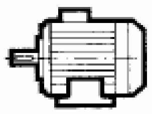
Hereafter are the (main) typical fixation modes with their identification letter

Example of designation IM 1001

IM	International Mounting
1	Fixation Mode
00	Position in duty
1	End of shaft type

Meaning of designations

Type of motor	Designation	Picture	Details
Motor with fixation **feet** *For any height of shaft*	**IM 1001 (IM B3)**		Horizontal shaft Feet on horizontal surface
	IM 1051 (IM B6)		Horizontal shaft Feet on wall on left viewed from drive end shaft
	IM 1061 (IM B7)		Horizontal shaft Feet on wall on right viewed from drive end shaft
	IM 1071 (IM B9)		Horizontal shaft Feet on top
	IM 1011 (IM V5)		Vertical shaft towards bottom Feet on wall
	IM 1031 (IM V6)		Vertical shaft towards top Legs on wall
Flanged (FF) motor with non threaded holes fixation *For any height of shaft* *Except for IM 3001 limited at*	**IM 3001 (IM B5)**		Horizontal shaft
	IM 3011 (IM V1)		Vertical shaft towards bottom

Type of motor	Designation	Picture	Details
225 mm of shaft height	**IM 3031 (IM V3)**		Vertical shaft towards top
	IM 2001 (IM B35)		Horizontal shaft Legs on bottom
	IM 2011 (IM V15)		Vertical shaft towards bottom Legs on wall
	IM 2031 (IM V36)		Vertical shaft towards top Legs on wall
Flanged (FT) motor with threaded holes fixation	**IM 3601 (IM B14)**		Horizontal shaft
	IM 3611 (IM V18)		Vertical shaft towards bottom
	IM 3631 (IM V19)		Vertical shaft towards top
	IM 2101 (IM B34)		Horizontal shaft Legs on bottom

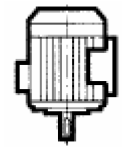
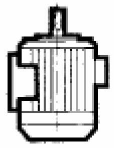
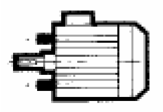
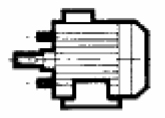
Type of motor	Designation	Picture	Details
	IM 2111 (IM V58)		Vertical shaft towards bottom Legs on wall
	IM 2131 (IM V69)		Vertical shaft towards top Legs on wall
Motor without drive end bearing *IP protection to perform when assembling motor with machine*	**IM 9101 (IM B9)**		Horizontal shaft Fixation with threaded rods
	IM 1201 (IM B15)		Horizontal shaft Fixation with threaded rods and with legs on bottom

Table 1: Frame construction and fixation codification for motors

Specific Motors for Hazardous Areas

See course EXP-MN-SE190 “Materials for hazardous Areas) developing this subject

In European Standard, the specific “Ex” classification determines 3 types of motors:

- “d” - Explosion proof or Flameproof
- “e” – Increases safety
- “n” – Non incendive

4.1.4. Protection Index “IP”

See, as well the course MN-SE190 where this subject is developed

4.1.5. Horsepower rating

The Horsepower (or Power in kW) indication on the nameplate is for:

- Interpretation of the rated output of the motor at full load
- Used to match the motor to the load
- Selecting the proper sized starter and disconnecting means
- Used to determine the motor full load amps if it is not given
- Size the conductors feeding the motor

The value indicated is for maximum load the motor can withstand.

Only Fan Motors are (by design) used at 100% of Load. *Of course a Ventilator can be equipped with a speed variation or with a mechanical system adjusting the blades angle; power being in those cases, modulated.*

On (nearly) all other applications, the machine coupled on the shaft needs to have a rated Power inferior of the motor rating (usually 80%), this to allow a hypothetic machine overload during a certain time.

Electrical connecting wires are sized according to the Motor Power rating

Electrical protections (thermal and magnetic amperes setting) ***can be sized to protect the coupled equipment, therefore having a trip setting less than the motor rating!***

In some design, several levels of trip are set, for the equipment and for the motor.

Example: a 10 kW (13.6 HP) motor is coupled to a pump developing 8 kW, the pump manufacturer recommends not to go above 8 kW, it can damage the pump. Thermal protection is to be calculated for 8 kW. And with U = 400V, cos phi = 0.85

$$\mathbf{Ith = Pw / U \times 0.85 \times 1.732 \;=\; 8000 / 400 \times 0.85 \times 1.732 = 13.6\ A}$$

4.1.6. Ambient Temperature - Altitude

This is the temperature surrounding the cooling medium that comes in contact with the parts of the motor.

A correcting factor (of the rated Power) has to be applied when the ambient conditions are different than the “base ones”, generally 40°C and average altitude of 1000m. Running conditions (speed) are (nearly) always indicated on the nameplate at a given Temperature.

Concerning correction for Altitude (generally not indicated), you can follow the graph hereafter or request complementary information from the manufacturer

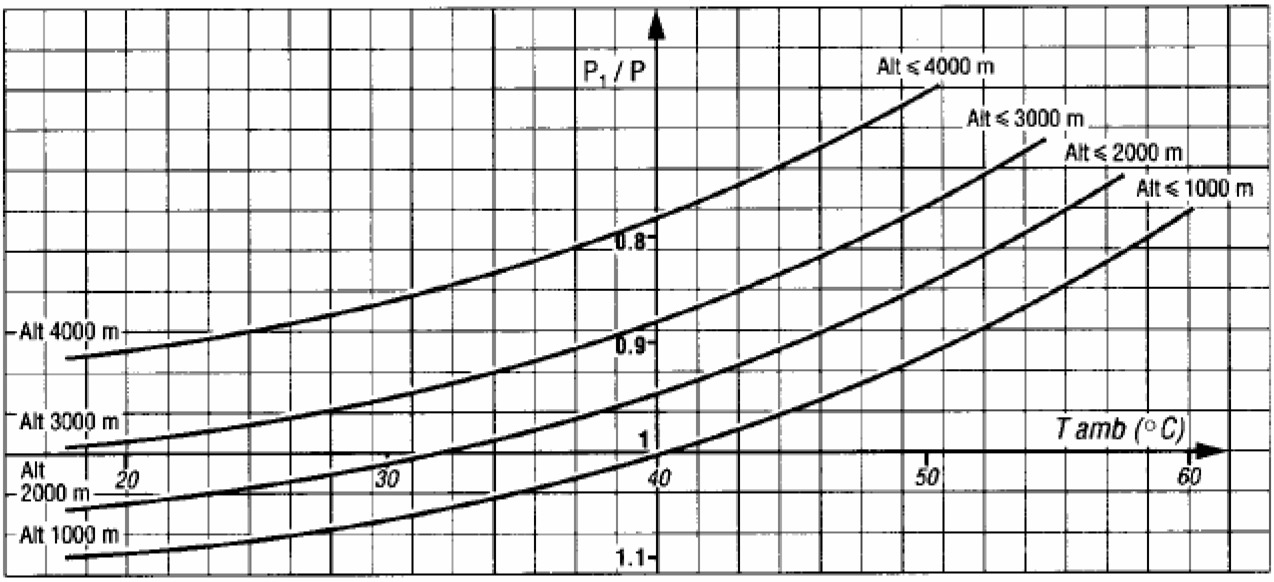


Figure 13: Correction factor for power with different Temperature and Altitude conditions

Temperature correction is also linked with type of insulation and cooling method. See on following paragraphs

4.1.7. Duty Cycle – Time Rating (Facteur de marche)

Either continuous or short time

Continuous means the motor can go on delivering its rated output continuously without over heating or damage

Short time ratings are given in 5, 10, 15, 30 and 60 min.
Motors with these ratings cannot supply the rated horsepower continuously

Supply the rated horsepower only for the time marked or listed

Facteur de marche / Running Factor: ratio between the time under power (with current passing and the time of cycle (running time + stop time)

The running Factor (*Facteur de marche)* is expressed in %.

For example, an electric hoist has its running factor indicated at 30%. Do not run it more than 3 min during an operating cycle of 10 min.

Number of starts: expressed either by

- Maximum number of start allowed during one hour
- Time to wait after one start (for HV motors mainly)
- Time to wait after “x” successive attempt to start

The control system of the concerned motor is (usually) equipped with necessary interlocks.

4.1.8. Service factor or Service Type

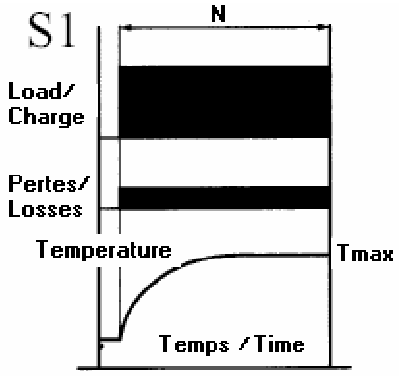
It is (more or less) associated with the duty cycle (*Facteur de marche*) as it is considering the parameters here above listed.

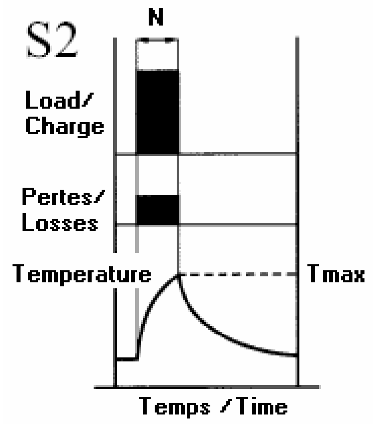
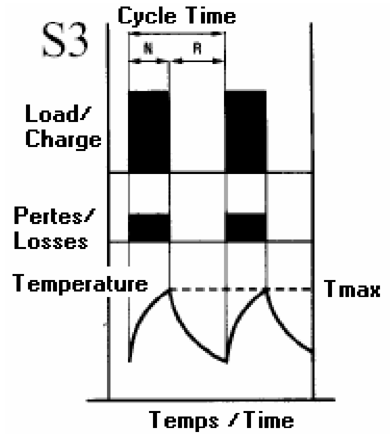
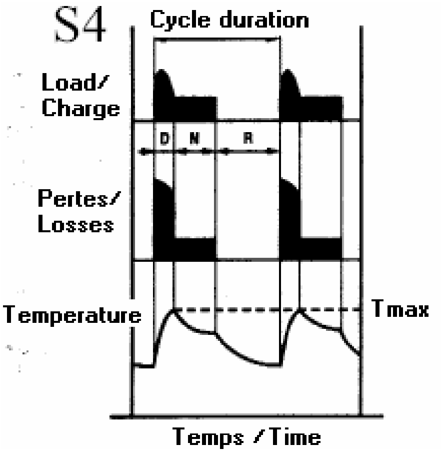
However this “service Type” (*facteur de Service ou type de Service*) is not based only on running time (of the motor), but it is considering numbers of other parameters and classified S1 to S10;

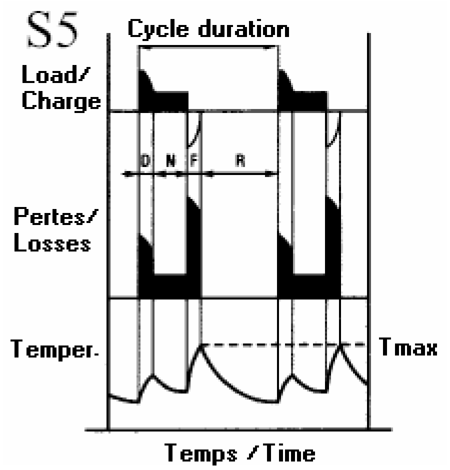
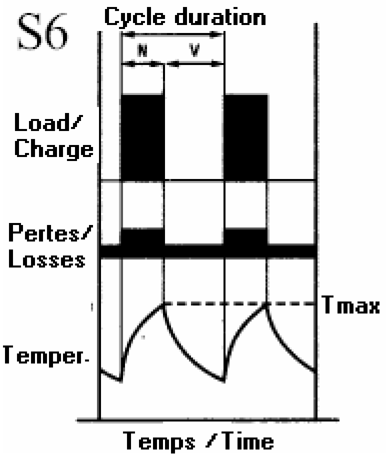
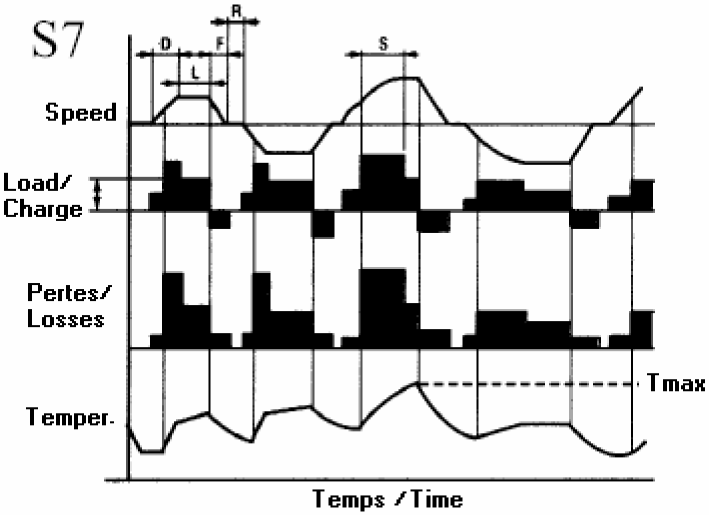
See the associated table explaining this classification.
Then, according to duty conditions, a “new” running factor / duty Factor (*Facteur de marche*) is issued

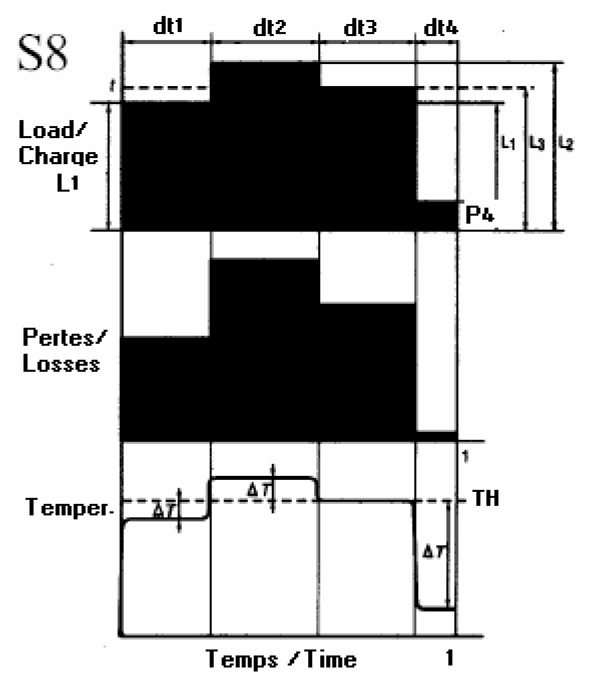
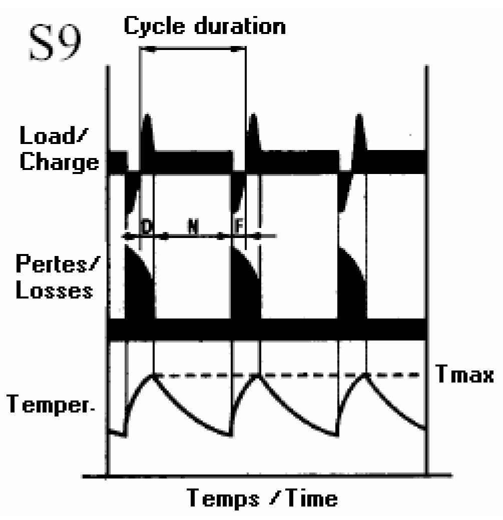
When the full load current rating is multiplied by this service factor/ running factor / duty factor / …., the product is the amount of horsepower the motor can deliver without generating excessive heat to damage the motor winding

See the table hereafter, then the use of the “magic” formula (and its legend) giving the ‘correction factor” for the rated power…. *(We consider Fdm – Facteur de marche = Fod – Factor of Duty)*

Service	Description
 S1 N Load/ Charge Pertes/ Losses Temperature Tmax Temps / Time	**Service type S1** **Continuous Service** Constant nominal Load during a sufficient time to allow thermal balance. Fod (Factor of Duty) = 1 and n (number of equivalent starts in one hour) ≤ 6.

Service	Description
 S2 N Load/ Charge Pertes/ Losses Temperature Tmax Temps / Time	**Service type S2** **Temporary Service** Constant nominal Load during a fixed time N, less than the one required to reach the thermal balance, followed by a rest time sufficient to come back in a 2°C gap between machine and cooling fluid temperatures Fod as per design and n = 1
 S3 Cycle Time N R Load/ Charge Pertes/ Losses Temperature Tmax Temps / Time	**Service type S3** **Periodical intermittent Service** Series of identical cycles including each a running period at constant Load N and a rest period R. In this Service, cycle is such that the starting current is not preponderant in the winding/machine increase of temperature Fod = N / N + R and n = 0
 S4 Cycle duration Load/ Charge D N R Pertes/ Losses Temperature Tmax Temps / Time	**Service type S3** **Periodical intermittent Service with Start** Series of identical cycles including a “long” starting period D, a duty period at constant nominal Load N and a rest period R. Fod = N + D / N + D + R and n as per design, replace n by 4n in the formula

Service	Description
 S5 Cycle duration Load/ Charge D N F R Pertes/ Losses Temper. Tmax Temps / Time	**Service type S5** **Periodical intermittent Service with electrical braking** Series of periodical cycle including each a starting period D, a duty period at constant nominal Load N, a braking “fast” period F and a rest period R Fod = N + D +F / N + D + F + R and n as per design, replace n by 4n in the formula
 S6 Cycle duration N V Load/ Charge Pertes/ Losses Temper. Tmax Temps / Time	**Service type S6** **Interrupted periodical Service with intermittent Load** Series of identical cycles including each a period of duty at constant nominal Load N, a pruning period at no-load V. No rest period considered. Fod = N / N + V and n = 0 Calculation is with the intermittent service formula
 S7 R D F L S Speed Load/ Charge Pertes/ Losses Temper. Tmax Temps / Time	**Service type S7** **Periodical non-stop Service with electrical brake** Successive identical cycles having each, a starting period D, a constant load running L, and electrical braking period No rest period Fod = 1 and n as per design, replace n by 4n in the formula

Service	Description
 S8 dt1 dt2 dt3 dt4 Load/ Charge L1 L1 L3 L2 P4 Pertes/ Losses Temper. ΔT ΔT ΔT TH 1 Temps / Time 1	**Service type S8** **Periodical non-stop Service with changes in Load and Speed** Series of identical cycles including each a period of duty at constant Load L1 corresponding with a fixed speed, followed by one or several duty period at other different Loads L2, L3, …corresponding to other different speeds. There is no rest period. Fod = 1 and n = 0, replace n by 4n in the formula. Calculation is also with the intermittent service formula
 S9 Cycle duration Load/ Charge D N F Pertes/ Losses Temper. Tmax Temps / Time	**Service type S9** **Non-periodical Load and Speed variations** Service in which Load and Speed vary non-periodically in the normal duty range. This service includes often overload which can be far higher than the nominal Load. For this type of service, overload and rated values have to be clearly considered at design time Fod = 1 and n = 0, replace n by 4n in the formula. Calculation is also with the intermittent service formula

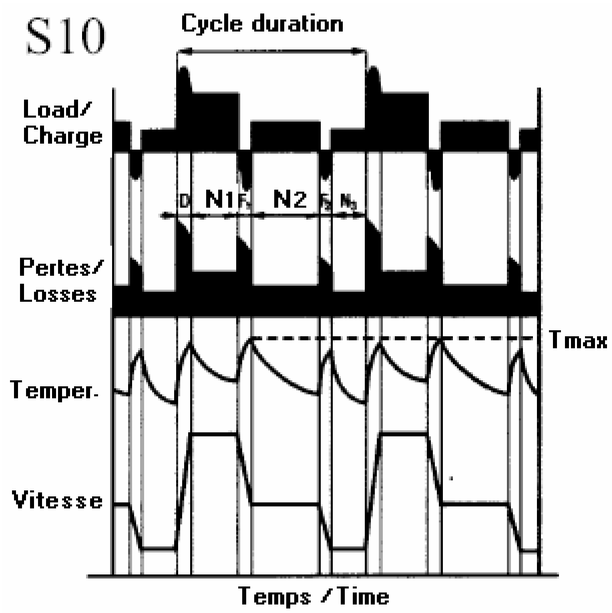
Service	Description
	**Service type S10** **Service with constant distinct duty periods** Service including at maximum four distinct Load values (or Load equivalent). Each (separate)e load has to be on duty at least a sufficient time to allow the reaching of thermal balance. The minimum Load, among the 4 values, can be at 0; *Running duty period with non load on the shaft or Rest period.* Fod = 1 and n = 0 Calculation is with the intermittent service formula

Table 2: The Service factor / type classification for an electric motor

Determination of the "apparent" Power Pa (resulting or corrected power would be more adapted), function of the different services S2 to S10 as per the following formula. *(Don't worry; it is not a so difficult formula…)*

$$Pa = \sqrt{\frac{n.t_d.\left[\frac{I_d}{I_n}.P_n\right]^2 + (3600 - n.t_d)P_u^{\,2}.Fdm}{3600}}$$

Where

t_d : temps de démarrage avec un moteur de puissance **P_n** (s) / Starting Time with a motor having a rated Power **P_n**
n : nombre de démarrages équivalent par heure **$n = n_D + 3.n_F + 0.5.n_i$** / Equivalent number of start per hour
n_D : nombre de démarrages dans l'heure / Number of starts during the hour
n_F : nombre de freinages électriques dans l'heure / Number of electrical braking during the hour
n_i : nombre d'impulsion (démarrage incomplet jusqu'à 1/3 de la vitesse finale) dans l'heure / Number of starting impulses (incomplete start up to 1/3 of the rated speed) during the hour
Fdm : *Facteur de marche* (%) = durée de fonctionnement à **P_u** / durée totale du cycle / Fod : Factor of duty (%) = time of duty at **P_u** / total cycle time

I_d/I_n : appel de courant avec un moteur de puissance **P_n** / ratio between start and nominal current giving the call current coefficient for a power **P_n**
P_u : puissance utile du moteur pendant le cycle d'utilisation hors démarrage / Used power during the normal duty cycle, starting period excluded
P_n : puissance nominale du moteur pressenti / Nominal power of the concerned motor

And for ***the intermittent services***, here is the formula

$$Pu = \sqrt{\frac{P_1^2.t_1 + P_2^2.t_2 + ...+ P_n^2.t_n}{t_1 + t_2 + ...+ t_n}}$$

With:

- The **P_i** (for each *independent* power) les than **P_n / 2** has to be replaced (in the formula) by the **P_n / 2**
- No one **P_i** should be above **2 x P_n**
- The "real" starting do not exceed **5 s**
- The torque in starting acceleration period is always sufficient

4.1.9. Non-balanced Voltage

The variation in voltage would affect the operation of the motor and the nameplate values

REMEMBER!! Power varies proportional to the square of the voltage ($P = U^2 / R$)

Acknowledgement of non-balanced Voltages (in amplitude only)

It can be resumed by the table here in this paragraph

Calculation of this "unbalancing" (in %) is done considering the difference between the highest and lowest Voltage values

$$Unbalancing(\%) = 100x\frac{V\max - V\min}{\frac{V_1 + V_2 + V_3}{3}}$$

	Value of unbalancing in %			
	0	2	3.5	5
Stator current	100	101	104	107.5
Increase of Joule loss in %	0	4	12.5	24
Temperature rise coefficient	1	1.05	1.14	1.28

Table 3: Unbalance of phases Voltage for motor supply

Once this unbalancing is known, it is advisable to apply a correction factor as per the graph

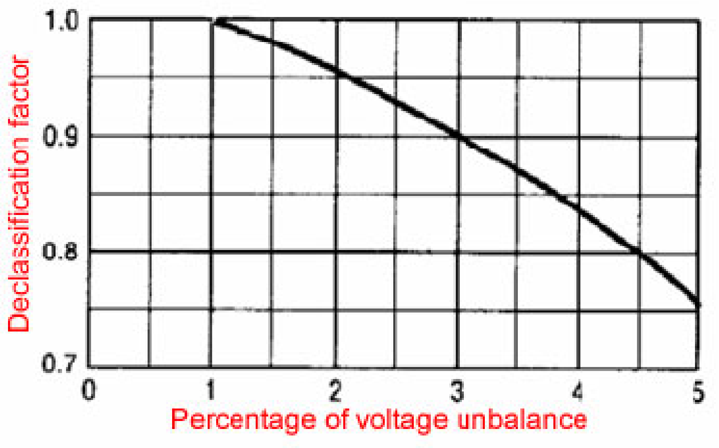


Figure 14: Correction factor for power as per % of Voltage unbalanced

Of course, this indication cannot be on the nameplate of the motor….

4.1.10. Speed rating – Slip

4.1.10.1. The synchronous speed

Already seen in operator course EXP-PR-EQ150 and seen as well in maintenance course EXP-MN-SE060 “generators”. We just remind here, the link between number of poles, speed and frequency.

The synchronous speed of the machine can be determined as follows:
1 revolution per cycle - 50 Hz supply this would give 50 revolutions per second for a machine with one pair of poles.

There are 60 seconds in a minute therefore the rotating field would do 50 x 60 = 3000rpm (the multiplication of N by 60 brings the answer to ***rpm*** rather than rps).

For motors with more than one pair of poles synchronous speed (N) is calculated by

N = f x 60 / P

With: **N** in rpm **f** = Frequency in Hz **60** = Seconds per min **P** = Pairs of Poles

The synchronous speeds for a 50Hz supplies are:

2 pole or (1 pair)	3000 rpm
4 pole or (2 pairs)	1500 rpm
6 pole or (3 pairs)	1000 rpm
8 pole or (4 pairs)	750 rpm
10 pole or (5 pairs)	600rpm
12 pole or (6 pairs)	500rpm

In a synchronous machine (motor here), the magnetic field of the stator is running at the same speed that the one of the rotor.

4.1.10.2. The asynchronous speed

On the nameplate of a squirrel cage motor, you can read, for example (taking only the data interesting us in this: paragraph)

50 Hz 4 poles Speed = 1470 rpm

It means that at rated load (HP or kW), the motor (rotor) run "only" at 1470 rpm when its rated synchronous sped (the stator magnetic field) is running at 1500 rpm. There is a difference between the stator and rotor speed which is called the ***slip (of 30 rpm here).***

This machine is called also an asynchronous motor, and under normal operating conditions the rotor of an induction motor (other name) will:

Never rotate at the synchronous speed of the rotating magnetic field.

The slip is usually referred to be the "fractional slip", which is normally expressed as a percentage of the stator speed.

At the moment of switch on the slip could be said to be 100%, slip valves vary from machine to machine and also according to the load being applied to the motor.

At no load slip is very slight; usually less than 0.1% of the stator synchronous speed, while under normal load conditions the slip would rarely exceed 0.5% for large machines.

Small motors (less than 10kW) may experience slip values approaching 3%.

This slip can be calculated by

Fractional slip = S = $\frac{Synchronous.Speed - Roto.Speed}{Synchronous.Speed} = \frac{Ns - N}{Ns}$

Example
Calculate the fractional slip of a three phase, four pole machine which has a supply frequency of 50Hz if the rotor speed is 1440 rev / min.

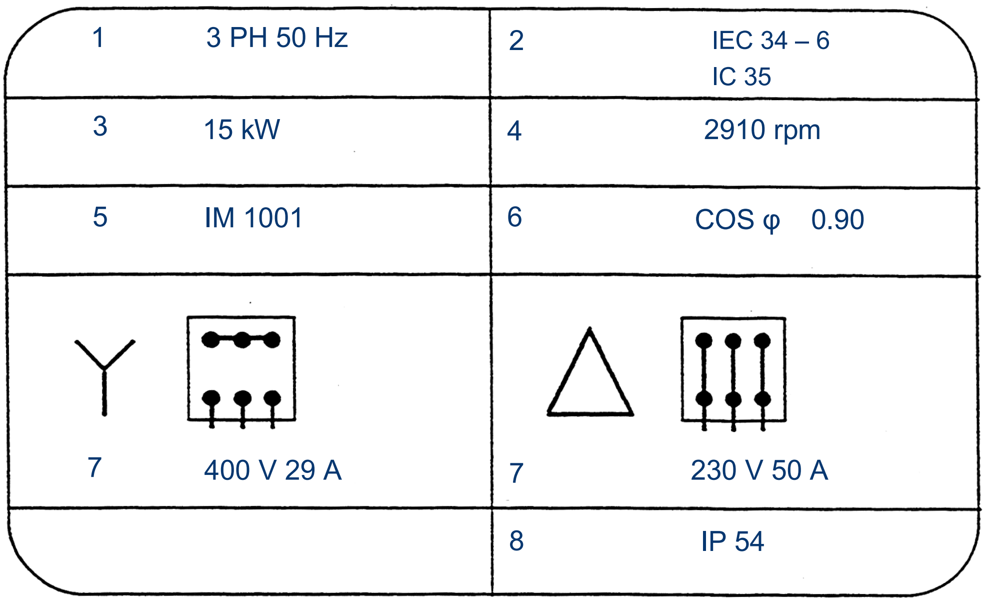
Solution
P = 2 (2 pole pairs), f = 50 Hz, N = 1440rpm

Ns = (f x 60) / P = (50 x 60) : 2 = 1500 rpm

S = (Ns – N) / Ns = (1500 – 1440) / 1500 = 60 / 1500 = 0.04

And in %: S = 4%

4.1.11. Example – Minimum Indications – on a nameplate



1	3 PH 50 Hz	2	IEC 34 – 6 IC 35
3	15 kW	4	2910 rpm
5	IM 1001	6	COS φ 0.90
7	400 V 29 A	7	230 V 50 A
		8	IP 54

Figure 15: Example (minimum) of a nameplate

1. Motor is three – phase for a 50 Hz supply

2. IEC 34 – 6 is a standard publication relating to motor cooling, IC 35 is a type of forced ventilation.

3. The normal motor shaft output is 15kw

4. The normal motor speed at rated output. From this can calculate the percentage slip. The motor is a 2-pole machine rated at 300rpm. The slip is therefore 3000 – 2910 = 90rpm. 90 ÷ 3000 = 0.03 = 3%.

5. IM (International Mounting) and four figures indicate the type of mounting. IM 1001 is a foot-mounted motor with two bearings and shaft with one gudgeon.

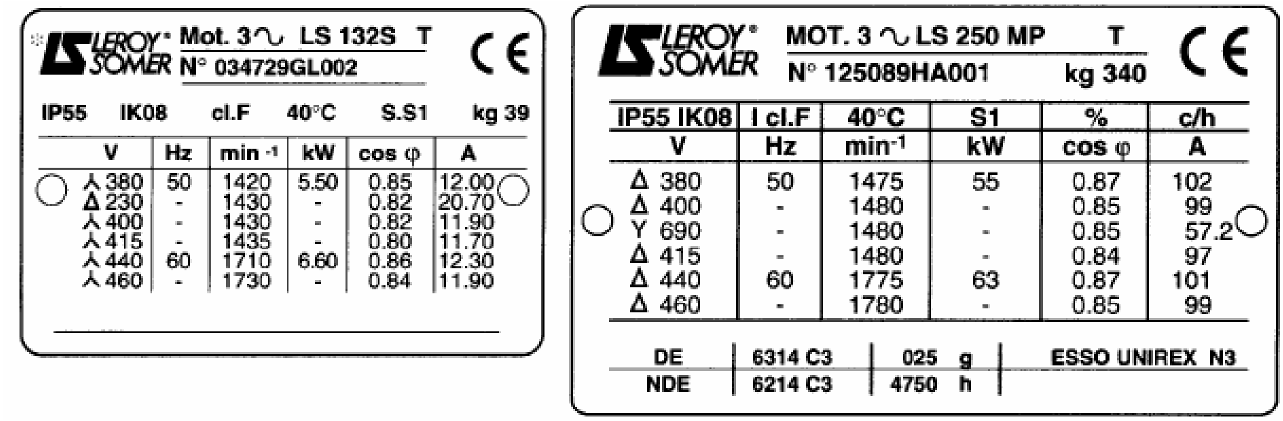
6. The power factor that the motor will run at when fully loaded.

7. The stator can be either star or delta connected. If the supply is 400V the motor should be **star** connected and the current will be 29A per phase, if the supply is 230V the motor should be **delta** connected and the current will be 50A per phase.

8. IP stands for Ingress Protection and the figures state the protection given against penetration by either solids or liquids. IP 54 allows limited ingress of dust and protection against water splashed in all directions.

4.1.12. Example – Complete Indications on a nameplate

As we have seen (nearly) all possibilities of marking, we can interpret the following (right one) nameplate. *For Insulation, Class of insulation and Cooling, see on next paragraph.*



Mot. 3~ LS 132S T
N° 034729GL002

IP55	IK08	cl.F	40°C	S.S1	kg 39
V	Hz	min -1	kW	cos φ	A
⅄ 380	50	1420	5.50	0.85	12.00
Δ 230	-	1430	-	0.82	20.70
⅄ 400	-	1430	-	0.82	11.90
⅄ 415	-	1435	-	0.80	11.70
⅄ 440	60	1710	6.60	0.86	12.30
⅄ 460	-	1730	-	0.84	11.90

MOT. 3 ~ LS 250 MP T
N° 125089HA001 kg 340

IP55 IK08	I cl.F	40°C	S1	%	c/h
V	Hz	min-1	kW	cos φ	A
Δ 380	50	1475	55	0.87	102
Δ 400	-	1480	-	0.85	99
Y 690	-	1480	-	0.85	57.2
Δ 415	-	1480	-	0.84	97
Δ 440	60	1775	63	0.87	101
Δ 460	-	1780	-	0.85	99

DE	6314 C3	025	g	ESSO UNIREX N3
NDE	6214 C3	4750	h	

Figure 16: Example (complete) of a nameplate

General Characteristics :

MOT.3~: Three phase AC motor
LS : Vendor identification
250 : Height of shaft
MP : Body identification
T : Insulation index
CE : Corresponds to standard CEI 34 / CE or EC for European Community
N° 125089 : Motor serial number
H : Year of manufacturing
A : Month of manufacturing
001 : Serial number in the series
kg 340 : Weight in kg
IP 55 IK 08: Protection Index
Classe F : Insulation Cass
40 °C : Maximum ambient temperature for normal running conditions
S1: Service type S1
% : Fod = Factor of duty (not specified)
C/H : Cycle per Hour (not specified)

Electrical nominal Characteristics :

Δ : Connections in Delta
380 V : Voltage supply
50 Hz : Frequency of supply
1475 min$_{-1}$: Revolution per minute
55 kW : Power
0 ,87 Cos ∏ : Power Factor
102 A : Nominal (rated) current

Other characteristics

DE : Bearing type on Driving End
NDE : Bearing type on Non Driving End
25 g : Weight of grease at each servicing
4750 h : Greasing Schedule
ESSO UNIREX N3 : Type of Grease

4.2. MAGNETIC AND POWER COMPONENTS

We have already seen numerous things and details, but here, we just (re)define the different principal parts and functions of a squirrel cage (induction) motor to “stabilise” our mind

4.2.1. Induction Motor

An induction motor is an alternating current motor in which the primary winding on one member (usually the stator) is connected to the power source and a secondary winding or a squirrel-cage secondary winding on the other member (usually the rotor) carries the induced current. There is no physical electrical connection to the secondary winding, its current is induced.

4.2.2. The Stator

That part of an AC induction motor's magnetic structure which does not rotate. It usually contains the primary winding. The stator is made up of laminations with a large hole in the centre in which the rotor can turn; there are slots in the stator in which the windings for the coils are inserted.

4.2.3. Stator Windings

Stator Core packs are primarily machine wound.

Synthetic resin covered wire is employed throughout.

The Insulation system allows for the accommodation of the maximum volume of copper conductor – the effective element of a winding. (See next paragraph)

This type of insulation covering is tough, flexible, resists ageing and abrasion.

Also resists moisture and other fluids.

4.2.4. Cage Rotor

Cage Rotors are primarily of die-cast aluminium construction.

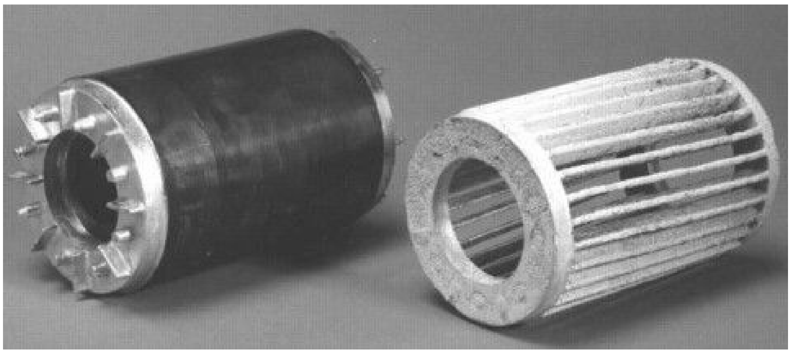


Figure 17: Squirrel cage Rotors

This comprises high purity aluminium, pressure die cast into the core packs to form conductors and endrings into a composite cage, and often, integral fan blades for heat dissipation.

Alternative constructions are of aluminium, copper or alloy conductors welded to similar, or the required end rings.

4.2.5. Rotor Shaft

Shafts are made of high grade steel, fully automatically machined to fine limits on all diameters and keywayed to receive the rotor cage. The shaft is also keywayed to accept a cooling fan and drive coupling with the shaft extension being drilled and tapped for the removal of the driving coupling, pulley or pinion, etc.

4.2.6. Bearings

Bearings are fitted to the shaft, once the correct size and fit are chosen.

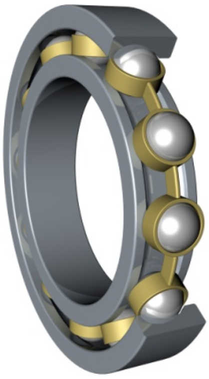
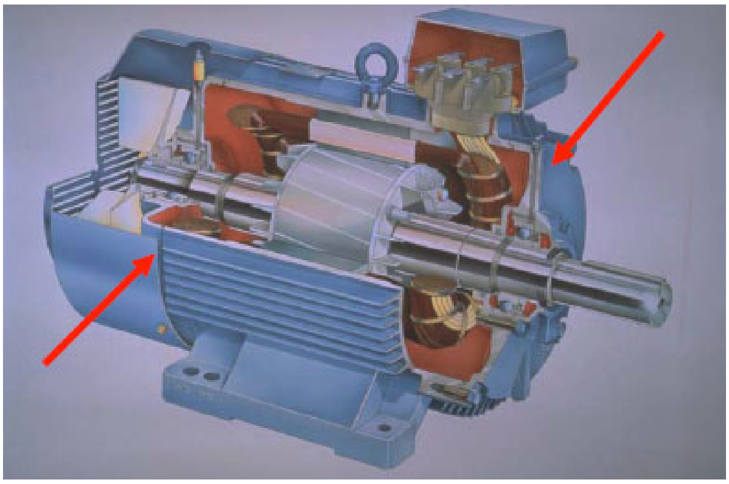


Figure 18: Typical Bearing

4.2.7. Endbells



Endshields or Endbells are primarily of die cast aluminium or cast iron. They are designed to give maximum rigidity in supporting the rotor assembly. The mounting spigots and bearing housings are machined to very close tolerances to ensure concentricity of the air gap.

Figure 19: Endshields or Endbells (flasques) of a motor

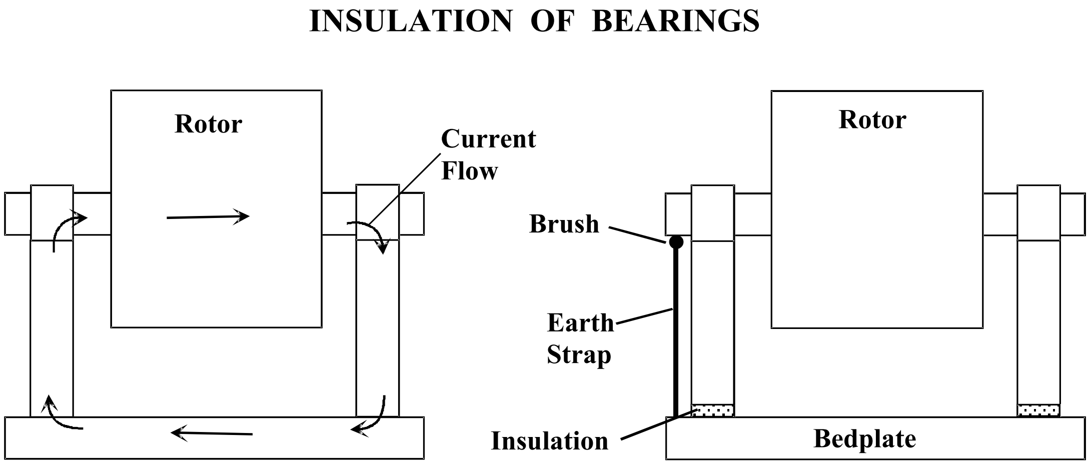
4.2.8. Insulated Bearings on shaft

Bearings of a large machine are often insulated to prevent stray currents from circulating through them. Such currents can arise from emf's being generated in the rotor shaft due to stray magnetic fields. Under fault conditions these stray fields can be very large. Figure, in this paragraph, shows how such currents may flow through the bearings.

These currents, if allowed to flow, would arc across the bearing surface and cause small craters (Galvanic corrosion). Figure shows pedestal sleeve bearings.

For reasons of safety the shaft must be at earth potential.

The insulation of the pedestal is carried out by a shim of insulating material between the base of the pedestal and its stool.



(a) UNINSULATED BEARINGS

(b) INSULATED BEARINGS

Figure 20: Insulation of bearings

4.3. INSULATION SYSTEM

Motor (and Generator) windings are insulated against the highest voltages to which they may be subjected, and the insulation must withstand a certain specified maximum temperature without deteriorating.

4.3.1. Insulation Rating

- Insulations are rated for their thermal endurance
- Used to properly select the winding conductors

- The following factors affect Insulation: Duty cycle, environmental conditions, frame type & enclosure, service factor and ambient temperature

4.3.2. Insulation Class

Class is function of the (maximum) Temperature to be accepted in the windings and consequently function of the used insulating materials (type and quality).

See hereafter, the table recapitulating the Classes ranking, a class being identified by a letter.

Class	Ultimate Temperature	Materials used	Comments / Description
Y	90°C	Cotton, silk, paper, etc, unimpregnated	
A	105°C	Impregnated cotton, silk, etc, paper, enamel	The rating is designed for use where a rise in continuous, full-load temperature will not exceed 60ºC over a 40ºC ambient temperature, and the hot-spot temperature will be no more than 5ºC over the normal rise. (This means a maximum conductor hot spot temperature of 105ºC.)
E	120°C	Paper, Laminates, epoxies	
B	130°C	Glass fibre, asbestos (unimpregnated), mica	This rating is designed for use where a rise in continuous, full-load temperature will not exceed 80ºC over a 40ºC ambient temperature, and where the hot-spot temperature will be no more than 10ºC over the normal rise. (This means a maximum conductor hot spot temperature of 130ºC)
F	155°C	Glass fibre, asbestos, epoxy, impregnated	This rating is designed for use where a rise in continuous full-load temperature will not exceed 105ºC over a 40ºC ambient temperature, and where the hotspot temperature will be no more than 10ºC over the normal rise. (This means a maximum conductor hot spot temperature of 155ºC)
H	180°C	Glass fibre, asbestos; silicone impregnated	This rating is designed for use where a rise in continuous full-load temperature will not exceed 125ºC over a 40ºC ambient temperature, and where the hotspot temperature will be no more than 15ºC over the normal rise. (This means a maximum conductor hot spot temperature of 180ºC)
C	> 180°C	Mica, ceramics, glass with inorganic bonding	

Table 4: Class of Insulation for windings of rotating machines

It should be noted that the classification letters do not follow an alphabetical sequence. This is because there were originally only three classes - ‘A ‘, ‘B ‘and ‘C ‘.

Most platform and shore-installed equipment’s are Class ‘B’ or ‘F’.

It does not depend on temperature rise alone; if, for instance, the ambient temperature is 40°C, a Class ‘B’ material may be used if the designed temperature rise will not exceed 90°C, so making the ultimate maximum temperature 130°C.

Quality of insulation is systematically controlled during maintenance, by measuring the values of windings isolation between phases and with the ground.

See Operator course EQ150 and last chapter of this course (maintenance), for information on this subject. (*Typical value of insulation, method of control, Polarisation Index,….)*

4.4. COOLING SYSTEM

All rotating machines used on platforms and in shore installations are **air-cooled and some, water-cooled** (generators).

For Te air –cooled, air is circulated past the stator and rotor windings by a fan on the generator shaft.

The warmed air itself may be discharged to atmosphere and not used again (“Circulating Air” or “CA”); or it may be water cooled in a separate cooler with a forced water circulation (“Circulating Air, Forced Water” or “CAFW”); or in a radiator-type cooler (“Circulating Air, Natural Water” or ‘CANW’).

The international coding system for cooling methods has been introduced for all rotating machines with Standard BS 4999, Part 21 and Standard IEC 34-6 and for codification of cooling type / method.

4.4.1. Identification of cooling

For identification of those methods, two systems of coding are used, one simplified for the common machines, the second one, more complete, for the elaborated systems of cooling.

The type of cooling is first identified by the letters ***IC*** (International Cooling), ***followed*** in the ***simplified*** coding by ***two or three numbers***, and with the complete coding by the letters ***IC*** followed by a group 2 or 3 letter/number (combined), renewed for each cooling circuit

Example: simplified coding **IC 411** or system complete **IC 4 A 1 A 1**

See applications in the following…

First digit code : Arrangement of Cooling circuit
0 - Free circulation
1 - Inlet duct ventilated
2 - Outlet duct ventilated
3 - Inlet and outlet duct ventilated
4 - Frame surface cooled
5 - Integral heat exchanger (using surrounding mediums)
6 - Machine-mounted heat exchanger (using surrounding medium)
7 - Integral heat exchanger (not using surrounding medium)
8 - Machine-mounted heat exchanger (not using surrounding medium)
9 - Separately mounted heat exchanger
Second digit : type/method of circulation
0 - Free convection
1 - Self-circulation
2 - Integral component mounted on separate shaft
3 - Dependent component mounted on the machine
4 - Spare
5 - Integral independent component
7 - Independent and separate device or coolant system pressure
7 - Independent and separate device or coolant system pressure
8 - Relative displacement

Table 5: Numbering codes system for cooling of rotating machines

4.4.2. Nature of Coolant

Where it is desired to specify the nature of a coolant, the following letter code is used in conjunction with the cooling code

Fluid nature	Letter	
Gasses	A	Air
	F	Freon
	H	Hydrogen
	N	Nitrogen
	C	Carbon dioxide
	L	Helium
Liquids	W	Water
	U	Oil
	S	Other Fluid (to be identified)
	Y	Fluid non selected….

Table 6: lettering codes system for cooling of rotating machines

4.4.3. Simplified Coding – Applications

Hereafter, some examples of simplified Coding

- The first number shows the arrangement (engineering) of cooling circuit

- The second shows the method used to provide the necessary energy for air circulation.

Code	Basic description
IC 01	Open machine Self cooling Fan fitted on shaft
IC 06	Open machine Fan cooler independent (autonomous)
IC 11	Self ventilated machine. Automatic air circulation. Fan fitted on shaft
IC 17	Forced air cooling. Air supplied at input and distributed through independent internal network
IC 21	Machine self aerated. Cooling air is forced at output. Fan fitted on shaft
IC 27	Cooling air is forced at output. Independent suction system assume air aspiration
IC 31	Self ventilated machine. Air is forced at input and output

Code	Basic description
IC 37	Self ventilated machine. Air is forced at input and output Air is supplied and distributed by an independent system
IC 41	Enclosed motor Forced ventilated air. External fan fitted on shaft
IC 51	Enclosed motor Tubes cooling One external fan and one internal fan

Table 7: Examples of cooling coding – simplified system

4.4.4. Complete Coding - Applications

Hereafter, some examples of complete Coding having two cooling circuits

- The first number shows the arrangement (engineering) of cooling circuit

- The first letter shows nature of primary fluid

- The second number shows the type of primary cooling circuit in the machine

- The second letter shows nature of secondary fluid

- The third number shows the type of secondary cooling circuit, external, being at the lowest temperature in the thermal exchanger.

Air and water are the most common cooling fluids.

They are codified respectively by the letters A and W/ Letter A is cancelled when air is the only (one) cooling fluid used.

Code	Basic description
IC 4 A 1 A 0 or IC 410	Enclosed machine Frame surface cooled. Air is circulated inside the machine within a closed circuit. Heat exchange only through frame surface
IC 4 A 1 A 1 or IC 411	Enclosed machine Frame / body aerated. External aeration is part of the motor. Air is circulated inside the machine within a closed circuit. Heat exchange only through frame surface
IC 5 A 1 A 1 or IC 511	Enclosed machine with integrated (inside) heat exchanger (tubes type). Two fans forcing air: the internal one circulating/extracting hot internal air, the external fan forcing ambient cooling air through the exchanger
IC 4 A 1 A 6 or IC 416	Enclosed machine with frame aerated by independent fan system fitted on this same machine. Internal air circulates freely inside in closed circuit (internal self means) and exchange heat through frame surface.
IC 3 A 1 W 7	Motor with air pulse cooler, water exchanger integrated. Air circulation is assumed by internal means of the motor. External (exchanger) cooling fluid has its own forced circulation (pump or free distribution)

Table 8: Examples of cooling coding – complete system

The typical (basic) squirrel cage motor used on site is (generally) of type IC 41 or IC 411

4.4.5. Exercises

Hereafter are 4 examples/4 pictures which were in the Operator Course EXP-PR-EQ150, paragraph 12.2.2.: *give the "proper" coding for each type of motor……*

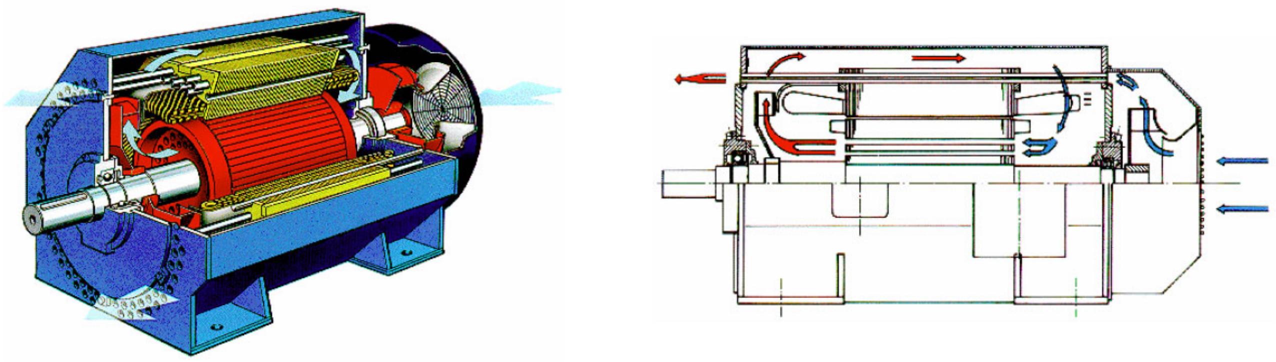


Figure 21: Motor with Air-Air exchanger

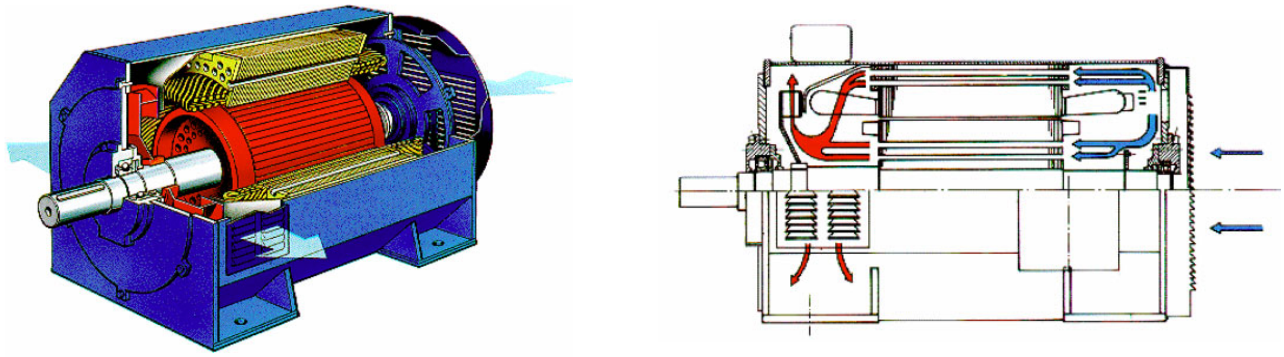


Figure 22: Open motor with or without filter

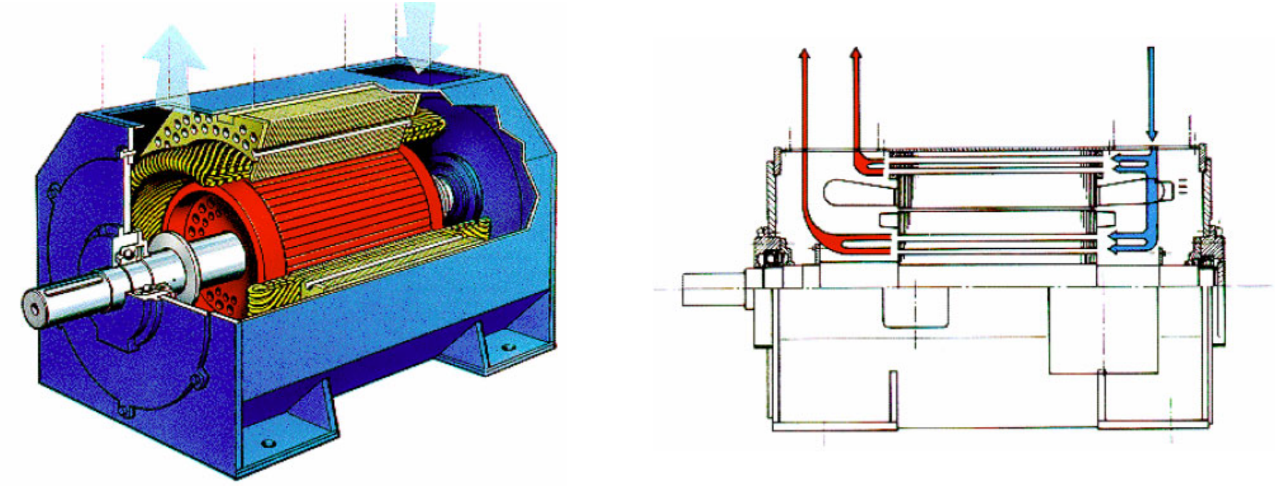


Figure 23: Motor with Air pulse cooler

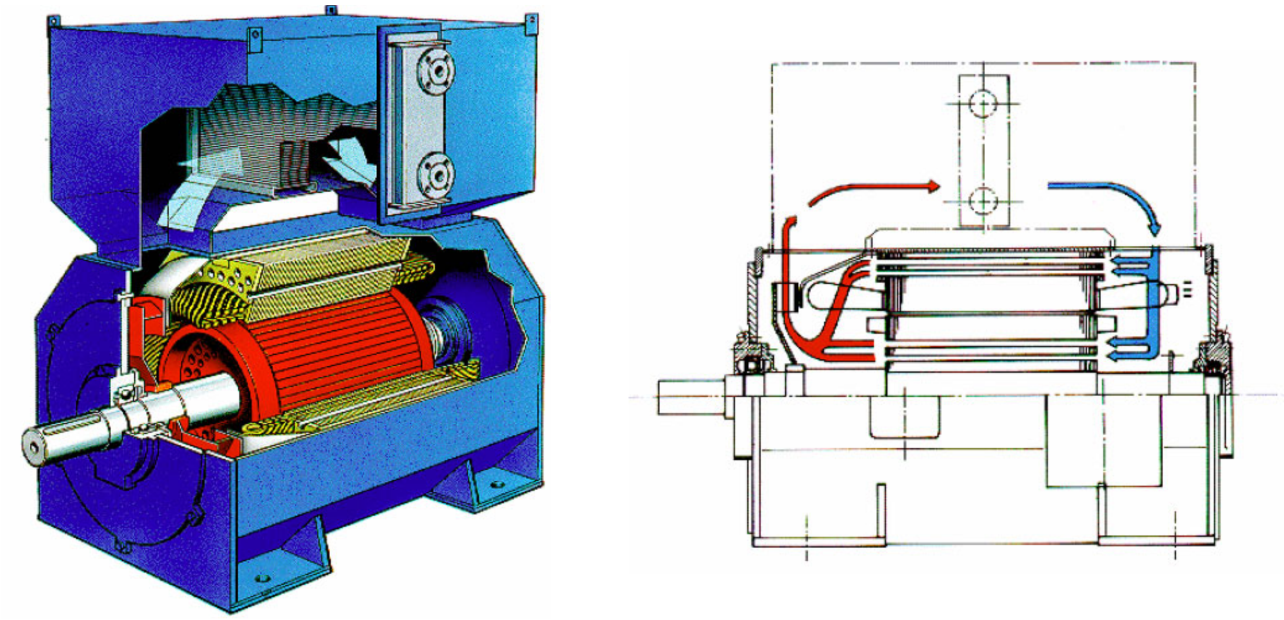


Figure 24: Motor with Air-Water exchanger

4.5. TERMINAL LAYOUT

We have already seen the different possibilities of windings connections in operator course EXP-PR-EQ150 in chapter 12. We just review it here

The following terminal configurations are only a guide to the more common variations .If in any doubt, ask someone “who is supposed to know” or consult the manufacturer (and/or its maintenance booklet) for advice.

4.5.1. Three Terminal

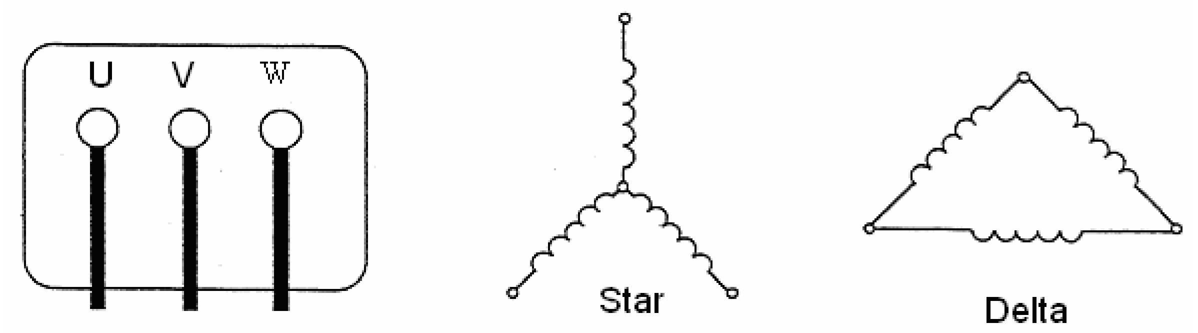


Figure 25: Connection directly on 3 terminal in the connection box

This is the simplest three phase connection type and is found on machines, which are internally connected in star or delta (as shown). Reversal is achieved by changing any two phases around.

The nameplate must show on which voltage this concerned motor is to be used, there is only one possibility, one voltage designed for; you have no access to modify the internal connection either Star or Delta (not necessarily indicated on the nameplate).

4.5.2. Four Terminal dual Voltage Motor

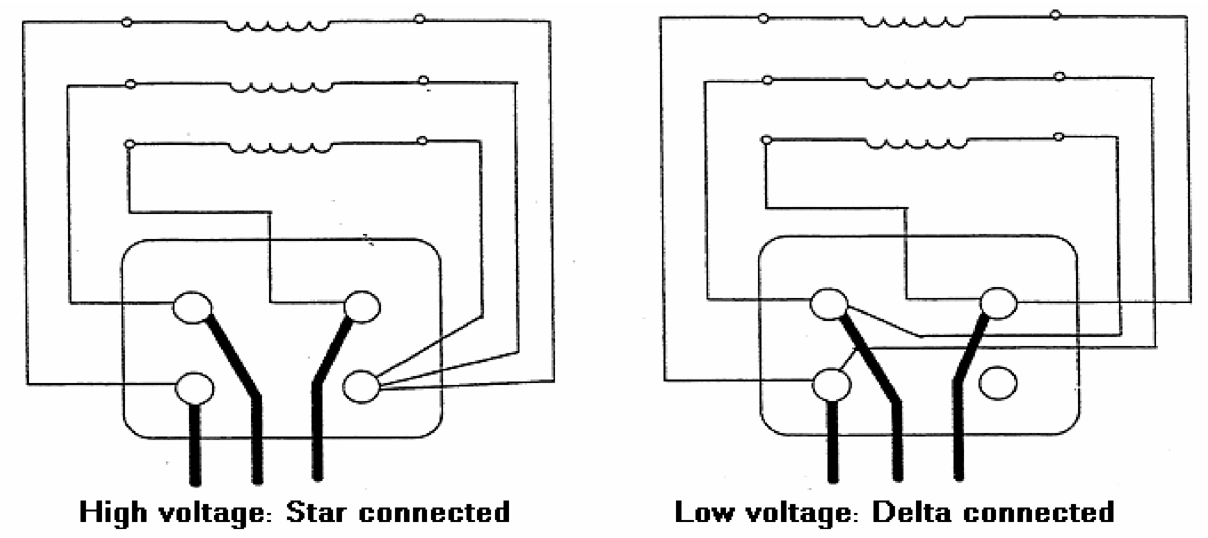


Figure 26: Four Terminal Connections – Dual Voltage Motor

This four terminal connection block is often found on smaller machines to provide a dual voltage facility, the terminal arrangement allowing connection in either star or delta. Note in delta the forth terminal is not used. To reverse change any two supply phases around.

This type of terminal connection is not often encountered in our sites applications, but you can find it, and do not be surprised in that case.

The 3 phase windings are connected together on the forth terminal (Star for Higher Voltage). If you need the Delta connection, you have to disconnect those 3 wires et reconnect on the “appropriate” other terminals.

4.5.3. Six Terminal Motor

The “basic / classic / typical” connection

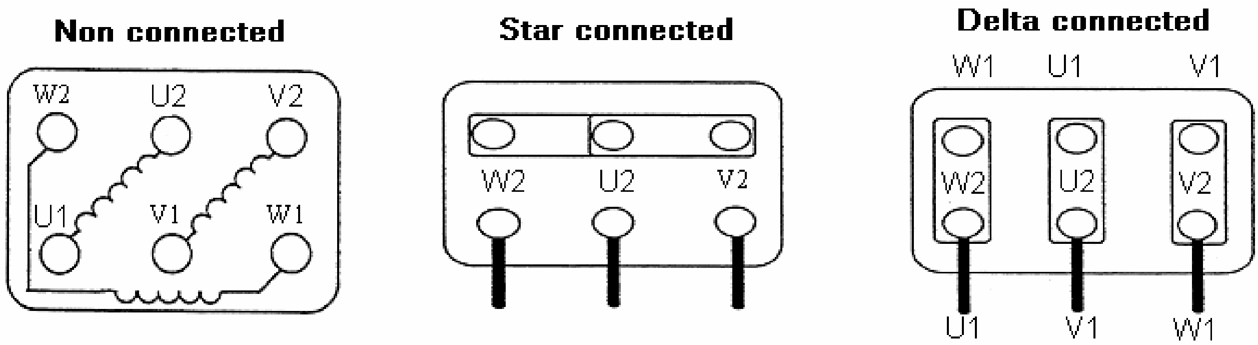


Figure 27: The basic six terminal connections

This is the conventional way of connecting the windings in a six terminal machine. The windings are staggered in order to simplify linking when delta connected.

A six terminal machine can be connected in either star or delta by linking the terminals as shown above; the staggered winding connections allow easy linking for star or delta connection. The rule is never having like winding connections opposite each other. To reverse change any two supply leads around.

The Standard identification letters are U, V, W (either capital or minuscule) and numbers 1 and 2 for each ends of each winding. Order 1, 2 has to be well respected (and known) for not having one phase in opposition.

If you have to reconnect the six wires on the terminal box and you are not sure of the ends numbers (1 or 2), inject DC current in one winding (from your multimeter, position ohmmeter should be sufficient) and check direction of magnetic field inside the motor (generally you do that when servicing / maintaining with stator / rotor separated) with a magnetic needle / pointer. Does it for the 3 phases for having rotation of pointer in the same direction, you then have the 3 windings polarities determined…

4.5.4. Other Connections

See Operator Courses EXP-PR-EQ150, paragraph 12.1.3 about the still six terminal box, but with “specific” internal winding connections giving the possibilities of having Low and High speed according the connections and supplies on the terminal box *(Dahlander connections – system with separates windings).*

For ***nine and twelve terminal connection***, please check with the manufacturer notice or the project / commissioning documents; Depending the “arrangement” of the different windings, it give possibilities of several speeds, several voltages supplies, several torques, …etc…

5. THE MOTOR STARTER / PROTECTION

If we have an electrical motor, it is to get it running *(or rotating…).* The important phase in the operation of a motor is the starting one and in some cases the stop period, then, we just need to survey it watching for any abnormal happening. *(Like for a plane, important phases are take-off and landing).* Here, in this chapter, we just get familiar with the starting phase, analysing it in details its characteristics and learning *(or remembering, reminding)* the terms used

5.1. STARTING CHARACTERISTICS

In order to perform useful work, the induction motor must be started from rest and both the motor and load accelerated up to full speed.

Typically, this is done by relying on the high slip characteristics of the motor and enabling it to provide the acceleration torque.

Induction motors at rest, appear just like a short circuited transformer, and if connected to the full supply voltage, draw a ***very high current*** known as the ***"Locked Rotor Current".*** They also produce torque which is known as the "Locked Rotor Torque".

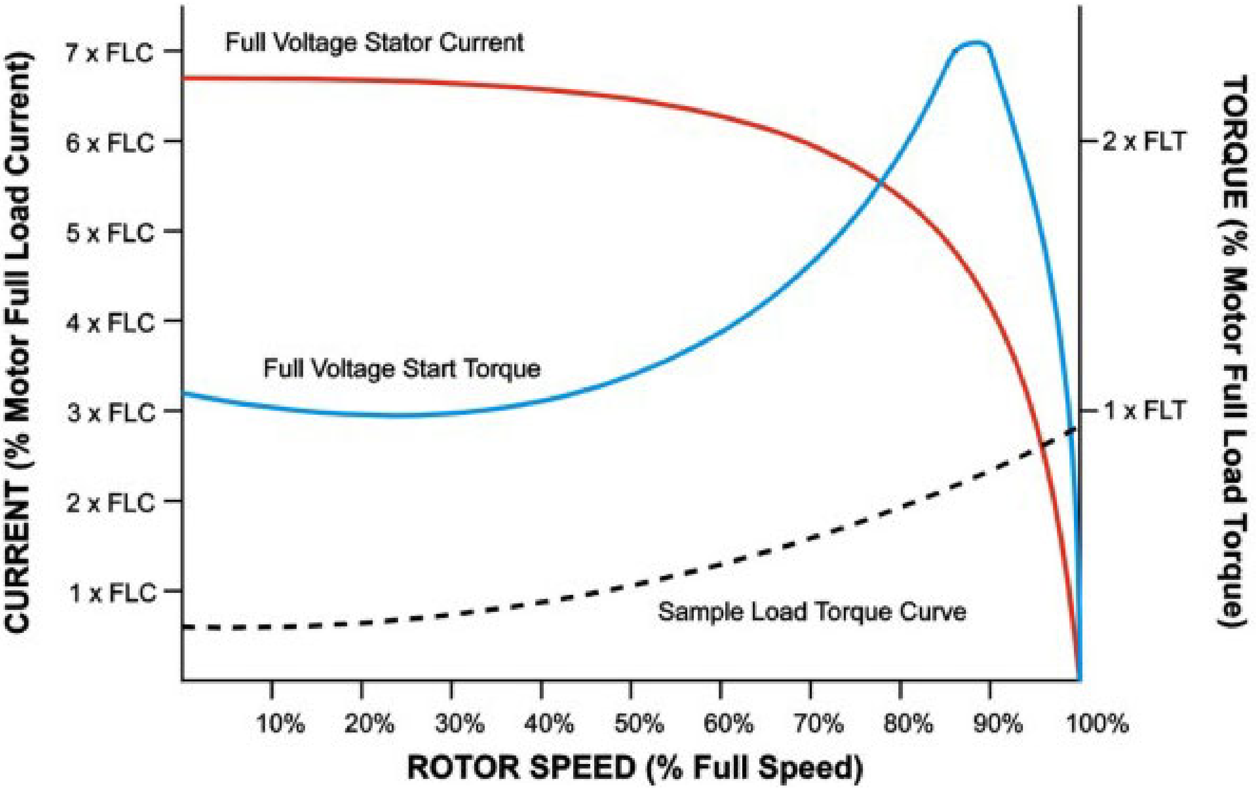


Figure 28: Typical starting curves of an induction motor (squirrel cage)

The Locked Rotor Torque (LRT) and the Locked Rotor Current (LRC) are a function of the terminal voltage to the motor, and the motor design.

As the motor accelerates, both the torque and the current will tend to alter with rotor speed if the voltage is maintained constant.

The starting current of a motor, with a fixed voltage, will drop very slowly as the motor accelerates and will only begin to fall significantly when the motor has reached at least 80% full speed.

The actual curves for induction motors can vary considerably between designs, but the general trend is for a high current until the motor has almost reached full speed.
The LRC of a motor can range from 500% ***Full Load Current (FLC)*** to as high as 1400% FLC. ***Full Load Current = Nominal Current = In***

Typically, good motors fall in the range of 550% to 750% FLC.

The starting torque of an induction motor starting with a fixed voltage, will drop a little to the minimum torque known as the pull up torque as the motor accelerates, and then rise to a maximum torque known as the breakdown or pull out torque at almost full speed and then drop to zero at synchronous speed.

The curve of start torque against rotor speed is dependant on the terminal voltage and the motor/rotor design.

The ***LRT*** of an induction motor can vary from as low as ***60%*** Full Load Torque (FLT) to as high as ***350%*** FLT.

The pull-up torque can be as low as 40% FLT and the breakdown torque can be as high as 350% FLT. Typical LRT's for medium to large motors are in the order of 120% FLT to 280% FLT.

The ***power factor of the motor at start is typically 0.1 - 0.25***, rising to a maximum as the motor accelerates, and then falling again as the motor approaches full speed.

A motor which exhibits a high starting current, i.e. 850% will generally produce a low starting torque, whereas a motor which exhibits a low starting current will usually produce a high starting torque.

This is the reverse of what is generally expected.

The induction motor operates due to the torque developed by the interaction of the stator field and the rotor field.

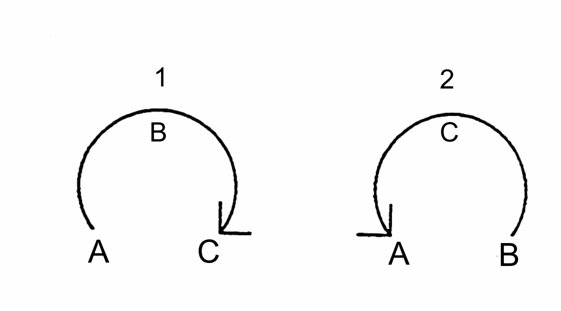
Both of these fields are due to currents which have resistive or in phase components and reactive or out of phase components.

5.2. THREE PHASE MOTOR REVERSAL

5.2.1. Reversing the rotation direction

To reverse the direction of three phase induction motor the direction of the rotating magnetic field of the stator must be reversed. This is done by reversing or crossing over any two of the supply leads to the motor. *(Like anyone already knows….)*

Reversal of the supply can be carried out using contactors on a reversing circuit where it is required for the motor to be reversed as part of the normal operation, or manually when the motor is not going in the desired direction.



The figure shows in a simplified form, the reversal of the rotating magnetic field by using the first three letters of the alphabet in order direction of rotation can be seen.

Figure 29: Example of Motor Reversal

1. ABC – clockwise rotation
2. ABC in this case gives anti – clockwise rotation – B & C have been changed over

5.2.2. Reversed Windings

This is (more) a happening which can occur when doing a miss operation or a wrong connection.

With a six wire terminal block one problem which may be encountered is a reversed winding, this is where the supply to one of the windings is the wrong way round, it is opposing the other two. The effect of this is that the motor will normally be noisier, the torque will be greatly reduced and the overload will probably trip.

If on start up the motor does not appear to be as it should be and the motor leads are not marked then:

1. Stop the motor right away.
2. Reverse the leads to one of the windings i.e. change over U1 & U2.
3. Try the motor again; if it is the same, stop the motor.
4. Reverse the leads to another winding i.e. V1 & V2.
5. Try the motor again, if it is still the same, stop the motor.
6. Change the first winding back, i.e. change U1 & U2 back.

The motor must be right after this third attempt, this example is showing the worst case and that is when the second winding is wrong.

If the first winding were wrong it would be corrected on the first change. If the third winding were wrong it would be corrected after changing one and two over.

Hopefully this procedure will never be needed as motors should be labeled correctly but in the event of the motor being unmarked the procedure can prove to be very useful.

5.3. PROTECTIONS

5.3.1. The Motor Starter

A motor starter includes all the components necessary to start/stop and to protect the motor. These components must be carefully selected and matched to ensure reliable operation, precise motor protection and safe maintenance.

An electrical motor can malfunction because of the following:

An electrical problem:

- Over voltage
- Under voltage
- Phase imbalance
- Single phasing (phase loss)
- Short circuit

A mechanical problem:

- Stalled rotor
- Momentary, or prolonged, overload

Any of these conditions can cause an increase in the current consumption of the motor, potentially causing the windings to overheat and damage the insulation, leading to motor failure through burn out.

5.3.2. Motor Starter Components

If the motor is to operate reliability, without damage, and we are to allow safe maintenance, starters must always incorporate the following:

1. An isolation device
2. A short – circuit protection device
3. A power-switching device
4. An overload protection device

This is the minimum requirement for motor protection, other protections can, of course, be added. Let us start with those "basic" protections seeing them in details hereafter.

However, we just enumerate them, with their functions. *For technological details see course EXP-MN-SE110 "Electrical Protections"*

5.3.2.1. Isolation device

This will have contacts, which open to cut off the main power supply to the control system and the motor, thereby ensuring safety for maintenance etc. It should be capable of being locked in the off position.

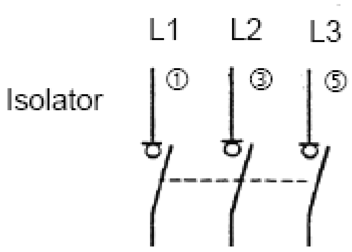
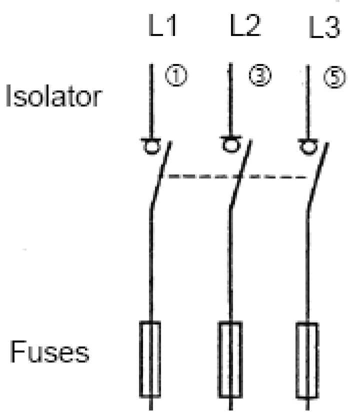


Figure 30: Isolation device - Isolator



Where an installation comprises several motor starters, they may not each be provided with a separate isolation device *(this is not recommended, but it happens….)*, however a main isolation device must always be provided to give general isolation from the incoming supply. Local isolators adjacent to the motors may also be fitted.

Isolator can be associated with fuses, either independent on a separate bracket (as on the figure), or being part of the isolator itself

An Isolator is not a switch, it has no breaking capacity. It has to be operated ***off load***.

An isolator is (generally) operated manually.

5.3.2.2. Short-circuit protection device

This should be capable of detecting and safely interrupting abnormal currents in excess of approximately ten times the motor full load current. This device will normally be High Rupturing Capacity (HRC) fuses (***type a.m.***) or a "magnetic device" integrated in a circuit breaker or a specific relay system. *(See course EXP-MN-SE110 for detail in fuses and relays))*

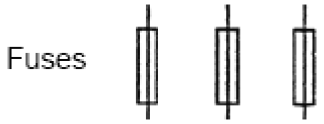


Figure 31: Short-circuit Protection by fuses

A magnetic protection can have a fixed set value - 5 to n times - the full load current (nominal current) or an adjustable setting.

5.3.2.3. Power switching device

This allows the supply to be switched on and off to stop and start the motor. It will normally be a contactor but on low cost applications it may be a snap – action mechanical switch. In other applications it could be a solid state contactor or a remote actuated breaker.

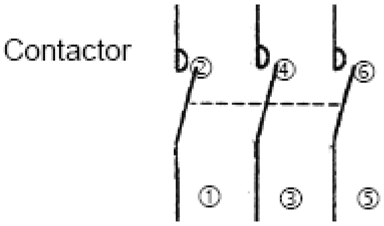


Figure 32: Power snitching device – the Contactor

5.3.2.4. Overload protection device

This should be capable of detecting abnormal currents up to “n” times (adjustable) the motor full load current and, in conjunction with a contactor, safely interrupting this current.

The objective is to prevent overheating in the motor windings, which could damage the insulation and lead to premature motor burn out. (The service life of a motor is reduced by 50% if it runs at 10°C above the rated temperature of its insulation classification).

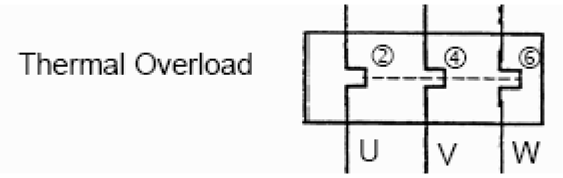


Figure 33: Protection by Thermal Overload

The ***thermal overload*** is the most common type. Other installations may have electronic protection relays, or thermistors *(considered as well as a thermal protection)* embedded in the motor windings to detect overheating. In addition to the above, extra devices may be provided to give enhanced protection or safety. These detect insulation breakdown, phase reversal, overheating of the motor windings, abnormal magnetic fields etc.

Thermal overload is (generally) set at 1,05 to 1,25 times the FLC (or In); but this value has to be adapted to the operating conditions. Check data sheets or vendor notice or any engineering document on that subject

Thermal overload is often associated with the “magnetic overload” on the same “magneto-thermal” relay (*block relay or relay system)* or breaker. *See course SE110*

5.3.2.5. Coordination between devices

Coordination is essential to ensure that the overload, the power switching device and the short circuit protection device (fuse or magnetic) all operate within their correct range of overcurrent.

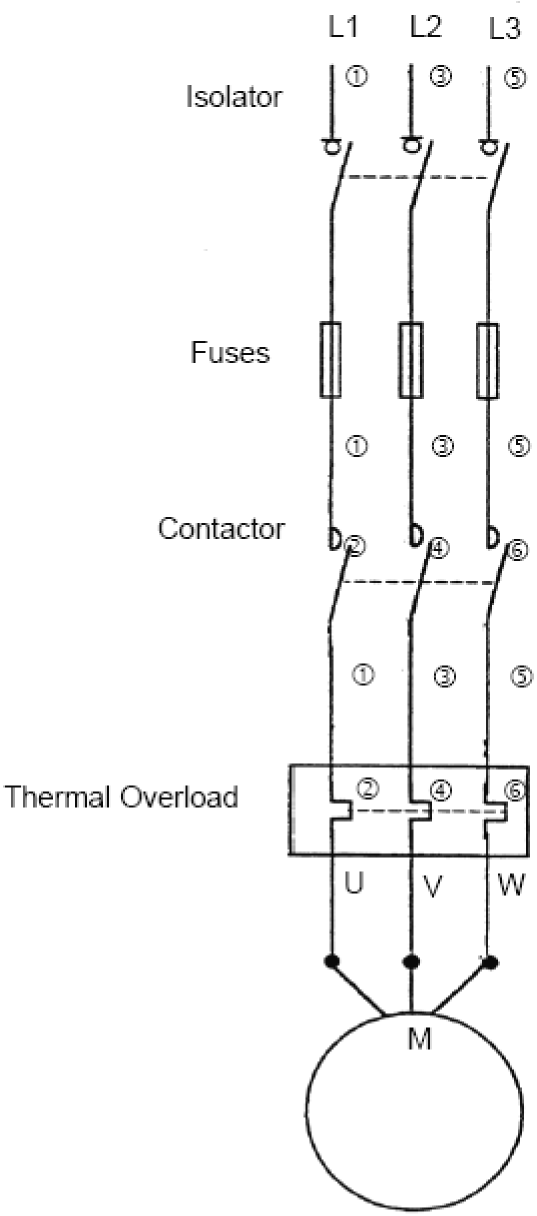


Figure 34: Typical motor starter protection (old system)

For a standard Direct On Line (DOL) starter using fuses, contactor and thermal overloads, the thermal overload normally operates at currents up to 1,05 to 1,25 FLC (as said above), with the fuse operating at (slightly) higher currents, to avoid redundancy.

Both thermal relay and fuses has to hold (a certain time) the starting current (5 to n times the FLC or In). However starting systems are now (nearly) all equipped with a starting current protection, the magnetic protection preventing too high values of this one. *See course SE110.*

Care must be taken that the ***current breaking capacity*** of the contactor (or breaker) is not exceeded, otherwise it may be damaged.

Different categories of contactors are available, classified as per the use / type of the starting system of the motor. Do not be surprised to see your contactor melting once you have chosen a "wrong" type of contactor. *See next paragraph.*

However, this type of motor starter produces (or produced…) a lot of problems resulting in motor burning…. When one fuse (and only one) blows off, and the control system do not detect it (*limit switch associated with the fuse as not worked due to mechanical / aging problem),* the motor continue to run, with two phases only ; and the windings does not like that….

A motor starter, nowadays (even if on Total site, it is not yet fully considered….), uses a breaker as thermal (and magnetic) protection, thus a problem one phase (overload) gives an immediate trip, the three phases being (mechanically) associated on a breaker).

I related already this "experience" in an other course: I used to work (as consultant) in a factory having this "classic" method of start (Isolator + Fuses + Contractor + Thermal - magnetic relay). They used to have, yearly, 60 cases of burned motors (all sizes). The year they replaced these protections by breakers, they had only 2 problems with motors.

Hereafter, example of (simple bur more efficient) protection called “motor – breaker”

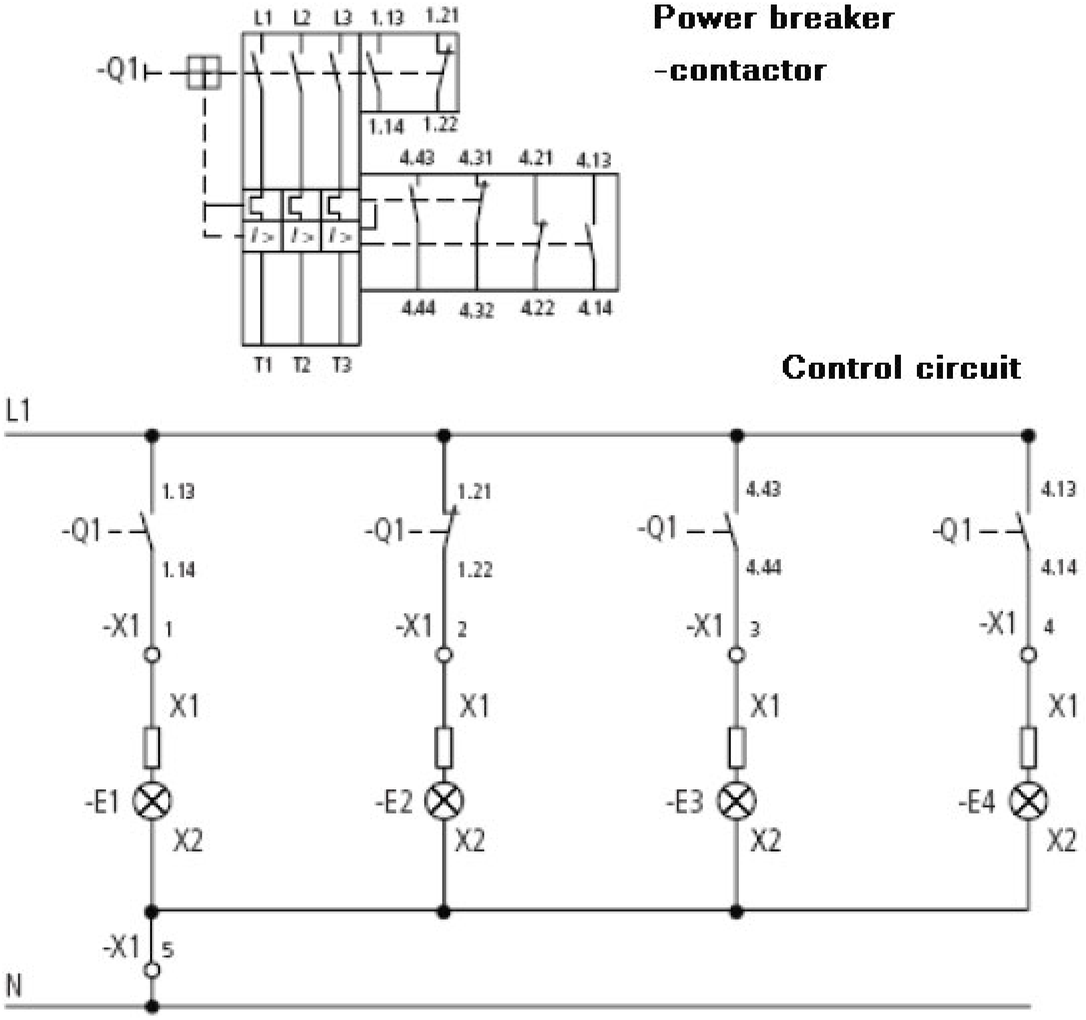


Figure 35: The motor-breaker protection system (overload thermal and magnetic)

In this (basic) schematic, the breaker is manually operated but of course automatically operated in case of thermal or magnetic overcurrent.

Question: interpret the use of each indicating lamp E1, E2, E3, E4

Answer:

E1: breaker close – motor on

E2; breaker open – motor off

E3: Trip by overload, action by thermal device

E4: Trip by short-circuit or too high current at start, action by magnetic device

5.3.2.6. Utilisation categories for AC switching

Contactors and switches may have different ratings according to the load they are subject to.

The standard utilisation categories define the current values which the contactor must be able to make or break

These values depend on:

- The type of load being switched: squirrel cage or slip ring motor, resistors,
- The conditions under which making or breaking takes place: motor stalled, starting or running, reversing, plugging.
- The power factor of the switched (equal or greater than indicated)

The table below gives the different categories. *(Once again); complementary information is on course MN-SE110.*

Utilisation Category	Typical Applications	Current (multiple of In*)				Power Factor
		Normal Conditions		Fault Conditions		
		Make	Break	Make	Break	
AC1	**Non- inductive or slightly inductive loads, resistance furnaces**	**1**	**1**	**1.5**	**1.5**	**0.95**
AC2	**Slip – ring motors starting – Plugging***	**2.5**	**2.5**	**4**	**4**	**0.65**
AC3	**Squirrel – cage motors, starting – switching off while running**	**5 to 7**	**1**	**10**	**8**	**0.35**
AC4	**Squirrel – cage motors starting – plugging* - inching***	**5 to 7**	**5 to 7**	**12**	**10**	**0.35**
AC21	**Switching resistive loads including moderate overloads**	**1**	**1**	**1.5**	**1.5**	**0.95**
AC22	**Switching mixed resistive loads including moderate overloads**	**1**	**1**	**3**	**3**	**0.65**
AC23	**Switching motor loads or other highly inductive loads**	**1**	**1**	**10**	**8**	**0.5**
AC11	**Switching electromagnets - transformers**	**10**	**1**	**11**	**11**	**0.7**

Table 9: Different categories for contactors

Note
In is the rated value of the effective current in normal operation.
Inching is energising a motor repeatedly for short periods in order to achieve small movements.
Plugging is rapid reversal of a motor by interchanging the phase winding while it is running.

And now, if you install an AC1 type contactor to switch on a squirrel cage motor having a start current, 6 times the nominal current, you can be sure to have problems…

5.3.3. Other typical motor protections

5.3.3.1. Centrifugal switch

As the motor accelerates centrifugal forces move the start winding contacts open

As the motor slows down the switch contacts close, ready for the next start

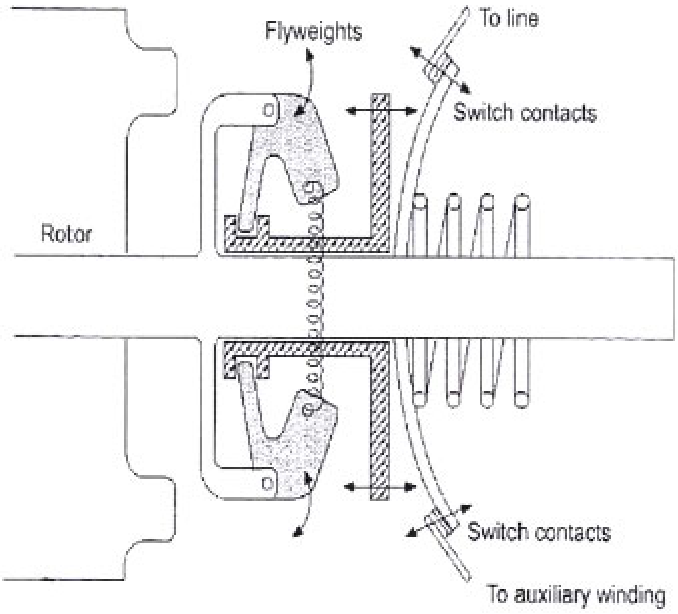


Figure 36: Centrifugal switch

Can be used as indication and/or as a safety device

- The motor has reached its speed
- The motor has not yet reached its (set) speed after a (set) time = problem = trip
- The motor has reached a (sufficient) low speed to switch-on in reverse rotation (plugging)

5.3.3.2. Windings temperature

Done either by thermal switch or a thermal sensing bulb (generally RTD type) transmitting an On/Off signal (the switch) and an analogue signal (the bulb) towards the control system

This, to protect against overheating of the machine. Several such sensors / detectors can be installed inside the windings, at construction, depending the size of the motor

When the motor is equipped with a simple switch a contact), it is up to the user to relay it as an alarm or a trip; With one or several analogue sensing element(s), up to the user to relay it in indication, alarm and trip at (more advisable) the recommended vendors values

5.3.3.3. Casing Heater

A fully independent thermal heater (resistance) is commonly installed on motors (and generators…) to keep moisture away when the motor is Off

The “heating” supply is generally done from an uninterrupted source, this to keep the heating on line when the plant is on shutdown.

This heating can be kept on line (sometimes) even with the motor running. Consequently, there is no systematic interlock between the two sources of power

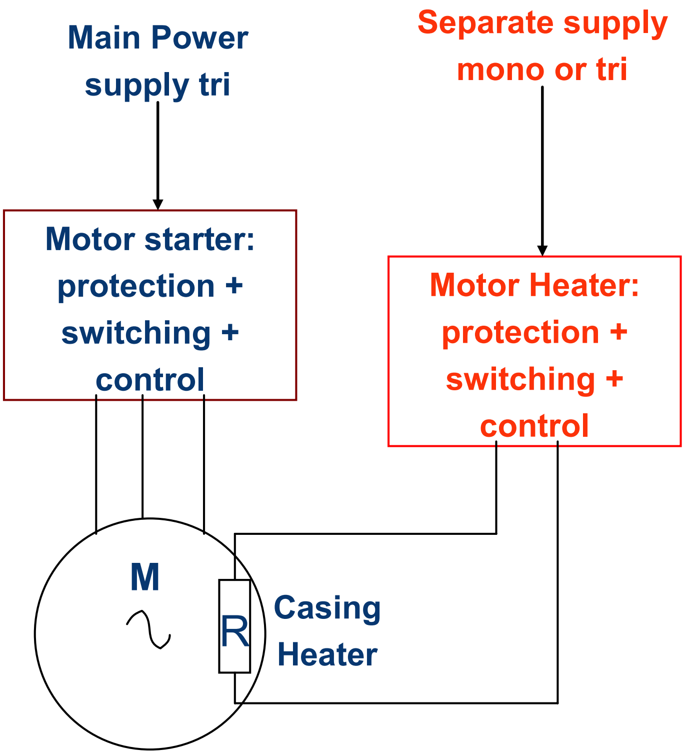

Main Power supply tri
Separate supply mono or tri
Motor starter: protection + switching + control
Motor Heater: protection + switching + control
M
R
Casing Heater

Figure 37: Casing heating system

Take care when working on the motor; do not forget to make ***two lock-off*** (consignation) ***procedures***.

Generally, the heating is done in 220VAC, for LV and HV motors. 220V is considered as a lethal value for voltage. I had seen some “incidents” on sites, with technicians forgetting this casing heating… Nothing fatal, but it could have been…

5.3.3.4. Heating with DC supply

Do not mix with the previous system and do not mix with the DC injection braking system (in following chapter

When the motor is stopped (of course), DC current is injected in the windings through the “normal” AC supply cable.

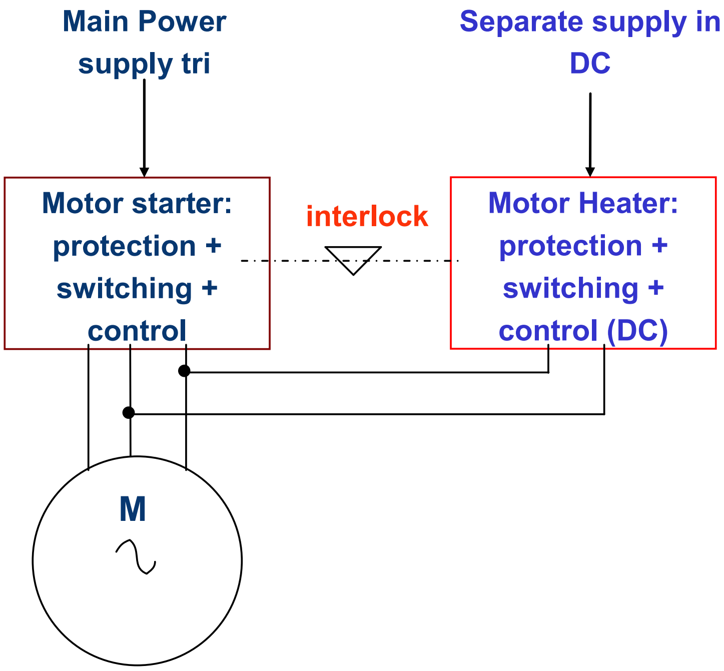

Main Power supply tri
Separate supply in DC
Motor starter: protection + switching + control
interlock
Motor Heater: protection + switching + control (DC)
M

Figure 38: DC supply for winding / motor heating

Between the two supplies there is automatically an electrical interlock associated (sometimes) with a mechanical one

5.3.3.5. Mechanical Protections

Motors for Hazardous Areas:

This a manufacturing specific design protection, see Course for operators EXP-PR-EQ150 paragraph 12.2.3 on that subject

Vibrations:

Motors can be equipped with axial or radial sensors detecting displacement and vibration.

This is (generally) part of a “vibration package”. See course EXP-MN-SM150 on that subject. *Vibration system has been decided to be on maintenance mechanical courses, but it could be “switched” to instrumentation courses in a “further arrangement”.*

5.4. THE BASIC ELECTRICAL MOTOR PROTECTION

We have already seen the “material” to use in the previous chapter (thermal and magnetic devices), we see as well the technologies of protections in course MN-SE110, let us (re)consider the reasons of having such protections and how to set / determine them.

5.4.1. Typical curves

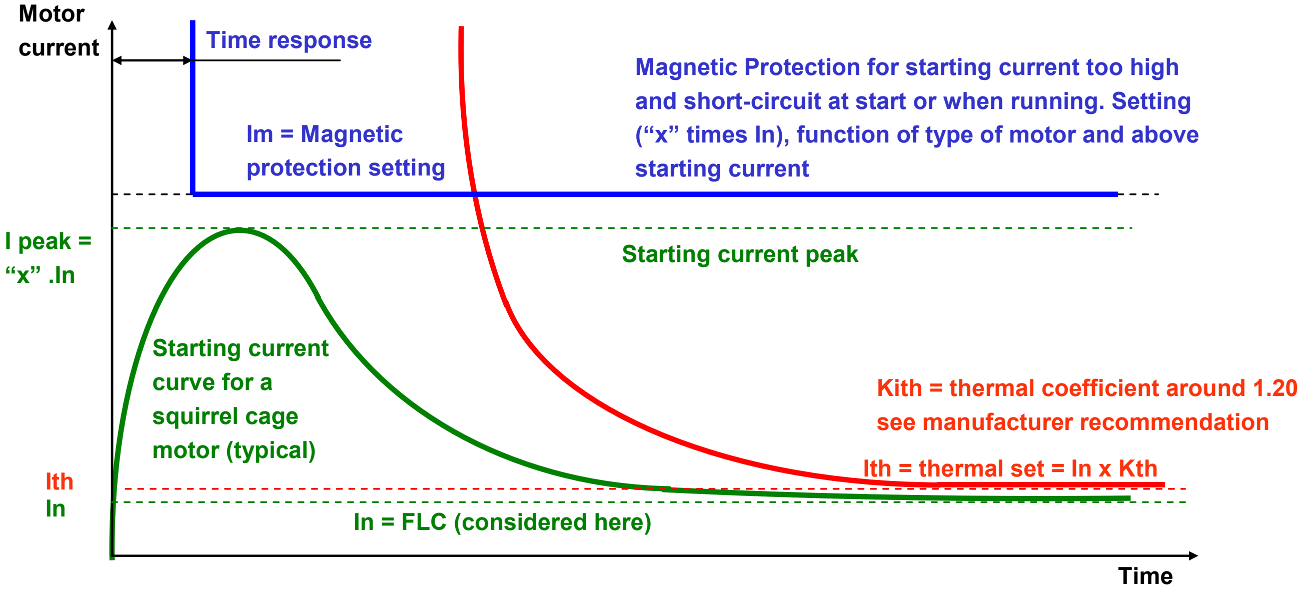


Figure 39: The basic starting curve and the protections

This is a typical behaviour of an induction motor at start. The peak current is as said above, function of the type of utilisation and the type of motor designed for.

The “at least” protections required to protect a motor are:

- Thermal overload protection generally set 10 to 20% above the rated current. This one can be the Full Load Current corresponding to the rated (maximum) power of the electrical motor or the operating current corresponding to maximum load which can be admitted by the driven equipment

- Starting overcurrent, detected by a magnetic system set above the maximum drawn current at start This protection reacts as well in case of short-circuit, at start or during normal running

Magnetic protection needs only a “short time” to react (average of 20 ms), it is (nearly) only function of the mechanical links action delay.

Thermal protection needs a “heating time” which can be as long as 10 min (generally far less) to reach the “horizontal line” corresponding to the set

A “slight difference” occurred when international Standards decided to represent the schematic protections, they inversed the axis……, to have this type of typical curve.

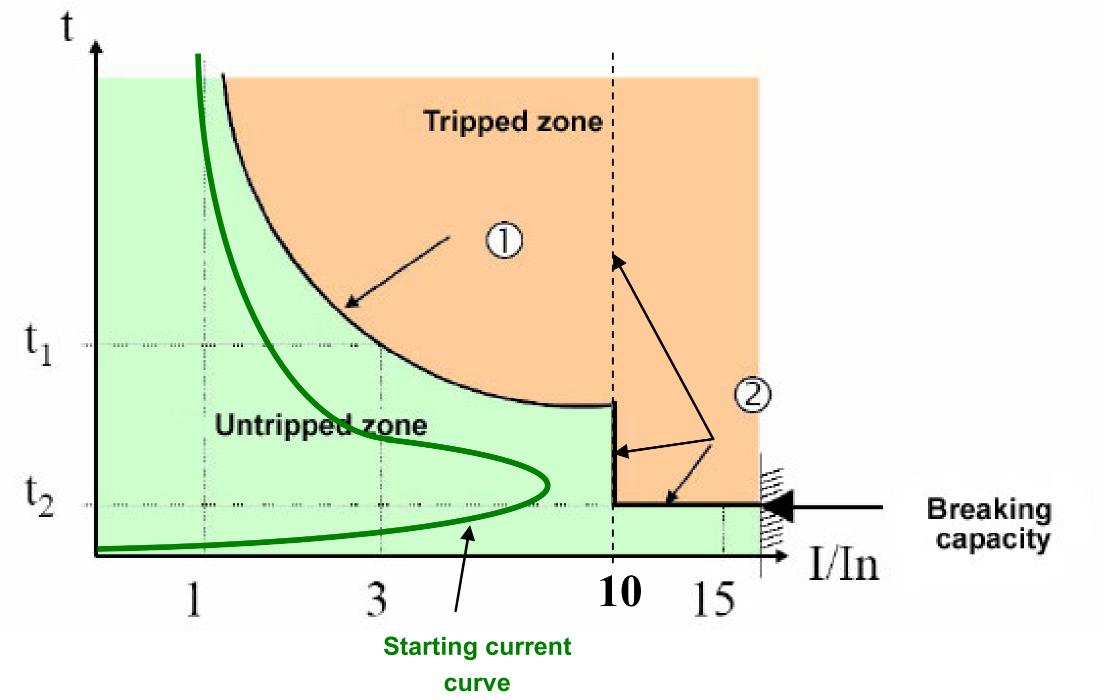


Figure 40: The basic protection curve for motor start protection

Legend ‘**1**’: nominal current, start period completed (I.start / In = 1)
‘**10**’: ratio I.start / In set at 10 for 10 times the Full Load Current, set point of the magnetic

①Image of the thermal device trip curve

② Image of the magnetic device reaction, limited by T2 , set at 10 times for protection first at start for overcurrent and in running conditions in case of short-circuit or "sudden" overcurrent

t2: delay of mechanical reaction of the tripping system, during that short period the switching device must be able to hold a short-circuit current (breaking capacity)

t1: if starting current is still at 3 times the nominal current, the thermal device reacts (equivalent to a too long start relay hereafter – next paragraph)
Note that both axis, horizontal for current and vertical for time are in logarithm scale.

This tripping curve can be seen on front of circuit breakers as represented on the figure for a standard 250 Amperes range breaker, we can see the adjusting knobs for thermal current (1) and magnetic current (2) as well as the "symbolic" tripping curve

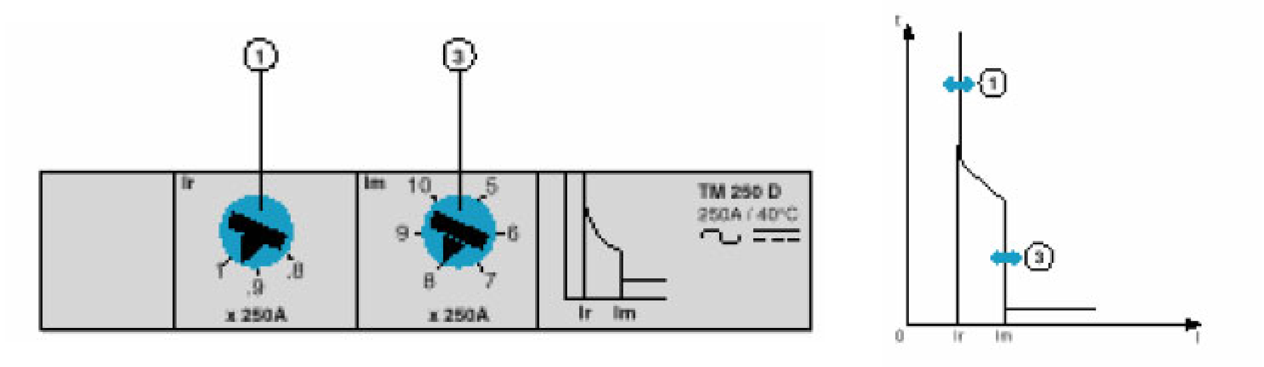


Figure 41: Adjustable thermal and magnetic trip unit on a breaker

See course MN-SE110 for extended explanations on this subject.

5.4.2. Protections for High Voltage and Low Voltage motors (above 75 kW)

Values of running parameters, for these equipment's are transmitted to specific relay hereafter enumerated, through CT's (Current transformers – in HV and LV) and PT's (Potential Transformers in HV)

Coding and functions of these protective relays are seen as well in course MN-SE110 among all the other type of protections. Here we just restrain us to the "Motor Protection"

Each Motor, with its own application has its set in all types of protections. Please refer to Motor and Load characteristics or (best way) refer to design / commissioning data sheets.

5.4.2.1. General protection relay

Manufacturers of protective equipment's have all a "general relay". On Total site, we have the Sepam 2000 (Schneider), the REM 54 (ABB), etc…..

For the protection of all types of motor, the use of digital multi-functions relays should include the following features

- A sophisticated thermal image
- A unit sensitive to the negative sequence component of current
- A unit that provides rapid elimination of all heavy duty multi-phase faults (short-circuit, positive sequence,…)
- A zero sequence overcurrent unit supplied either from toroidal (ring type or core-balance) CT or from the residual connection of line CT's (earth faults)

This multi functions relay, for a motor, is taking into consideration the following faults:

Functions of multi-purpose relay	**ANSI code**
Thermal image overload	49
Negative phase sequence overcurrent	46
Earth – ground fault	51G
Instantaneous overcurrent and /or short-circuit	50 / 51
Too long start / Locked Rotor	51LR
Overvoltage	59
Limitation of number of starts	66
Undervoltage	27
Undercurrent	37
Under and over power	32-2
Neutral displacement over voltage	59G
Earth fault	64
Additional relay(s)	
Undervoltage (can be on the main multi relay)	27
Temperature supervision from RTD probes	49
Under and over frequency (can be on main)	81
Reverse power (synchronous motor)	32
Etc, see course MN-SE110 for general view of all protections	

Table 10: Typical fault detections of a multi-functions relay for a motor

Standard protection scheme:

Hereafter is a graph / scheme representing all typical protection for a motor HV or LV (high power).

Detailed explanations about (main / principal) motor protections are listed and commented in the following

Note:

For ***Thermal image***, it can never be a well determined curve; it is between within a range limited by what are called on the scheme; the “cold curve” and the “hot curve”.

Short-circuit (1) and ***fuses*** (2) protections are redundant protections. Normally only one of those two is operating. See short-circuit protection explanation code 51

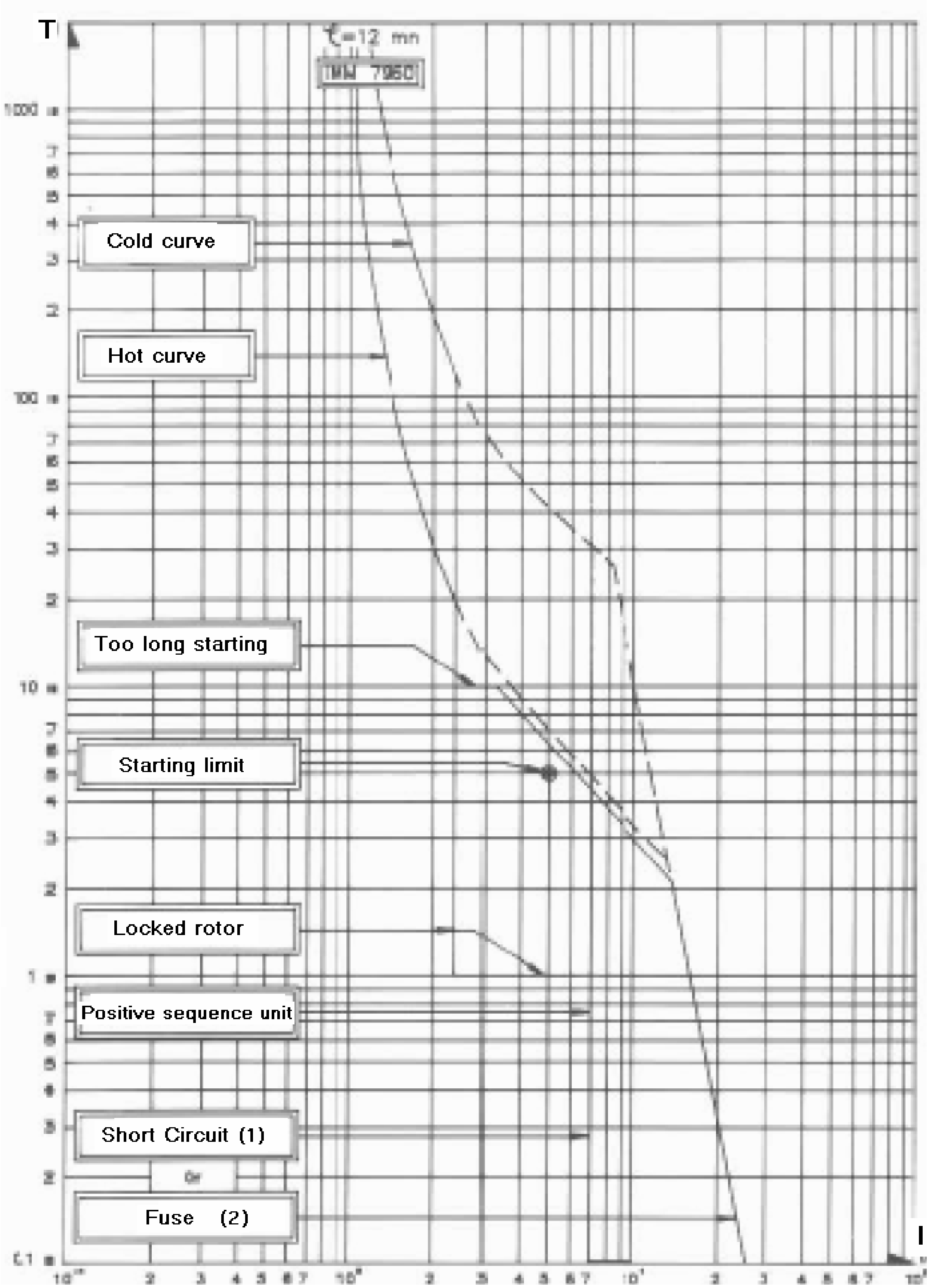


Figure 42: Typical protection types on induction motor starting curve

5.4.2.2. Balanced and unbalanced thermal overload (code 49)

Protection of equipment against thermal damage, caused by overloads.

Thermal overload is calculated according to a mathematical model, with 2 time constants, taking into account the effect of negative sequence current (*code 46 unbalance*) by means of an adjustable weighting coefficient:

- An adjustable setting to define motor warm state
- An adjustable tripping setting

The thermal overload protection is used to protect the machines (motor, generator, transformer...) against overloads.

To detect the existence of an overload, the thermal overload protection estimates the heating of the machine to be protected from the measurement of the current.

Starting of the motors and thermal overload protection

The thermal overload protection cannot be used against too long starting of the motors. Indeed, the inrush current of a motor is very high (6 to 8 times the rated current). Its heating is roughly proportional to the square of the current; it is thus very fast at the starting.

During starting, the calorific contribution is not completely diffused in the motor. Thus, the local heating on the level of windings and insulator can be excessive.

However, the thermal overload protection considers a total heat-storage capacity of the motor and an instantaneous calorific diffusion; it thus does not hold account of the local heating.

It results that thermal overload protection determines the heating caused by starting, but cannot protect the motor against a too long starting or a blocking of the rotor. There are besides specific protections for that (see 51LR). It is thus especially effective to protect from the slow overloads.

5.4.2.3. Unbalanced (46)

Protection of equipment against overheating caused by an unbalanced power supply, phase inversion or phase break, and against low levels of overcurrent between 2 phases.

The protection at component inverse is used to protect the rotating machines (motors or generator) against unbalance of high current value, which may deteriorate them.
When the currents of the three phases are not balanced, it appears a component inverse of current.

The spinning field corresponding to the component inverse induced a double frequency current (rotor) which causes important Joule losses. The overheating of a rotating machine by a permanent component inverse of low value (few percent) can be taken into account by an image thermal protection.

But, in the event of power supply on two phases only following by the fusion of a fuse or with the breakdown of a phase, the component inverse has a high value and can deteriorate the machine very fast; the thermal image protection is not quick enough

A component inverse protection protects the rotating machines against this type of anomaly.

Adjustment indication for the motors

Throughout starting, the motor absorbs a component inverse of current between 20 and 30 % of the rated current (*and 15% for the generator, few seconds delayed)*. To avoid inopportune release during starting, and to obtain satisfactory adjustments, it is necessary to use a protection at independent time with double threshold or a protection at dependent time.

5.4.2.4. Overcurrent (50)

Can be also considered as 50 + 51 (short-circuit)

This protection has the function to detect the single-phase, two-phase or three-phase overcurrents (and short circuit)

The protection is activated if one, two or three of the concerned currents exceed the setting corresponding to the threshold of adjustment.

This protection can be time lag; in this case it will be activated only if the controlled current exceeds the threshold adjustment during a time at least equal to the selected temporisation.

This temporisation can be at independent time or dependent time.

Independent time protection

The temporisation is constant; the protection is independent of the value of the measured current.

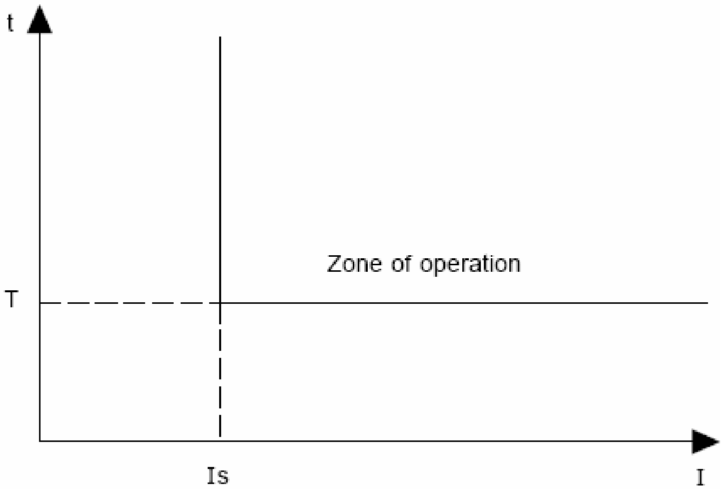


Figure 43: Independent time protection

Legend:
Is: *threshold of operation in current (threshold of current)*
T*: delay of the protection operation (temporisation)*

The threshold of current and the temporisation are generally adjustable.

Dependent time protection

The temporisation depends on the relationship between the measured current and the threshold of operation.

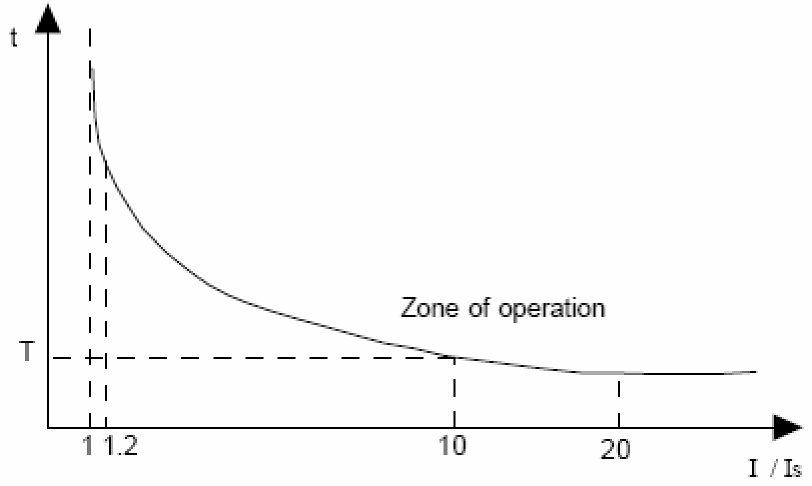
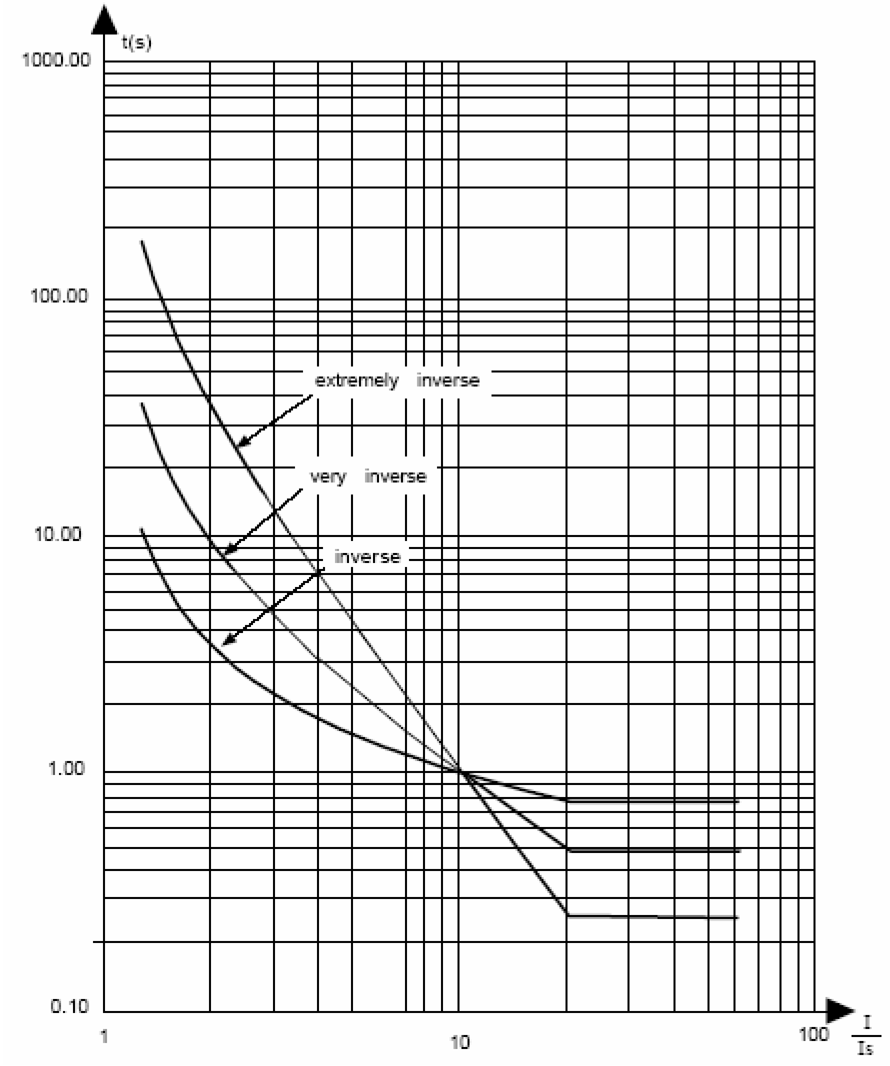


Figure 44: Dependent time protection

Legend:
***Is**: threshold of operation in current corresponding at the vertical asymptote of the curve.*
***T**: temporisation for 10 Is*



Higher is the current and weaker is the temporisation.

It can be defined several types of protection with dependent time, which are different following the slope from theirs curved: protection with inverse, very inverse or extremely inverse time.

For example, the Sepam 2000 of Schneider proposes the curves (of the figure) for a temporisation set at 1 second (temporisation of 1 second for I = 10 Is).

Figure 45: Curves inverse, very inverse and extremely inverse with T = 1 s

5.4.2.5. Short-circuits (51)

This detection can be done with the “overcurrent relay system” seen above, but it can be completed as well with the following devices, mainly for low power motors.

Protection against the low voltage motors short-circuits is done in general by aM fuses type. We will always take the precaution to check that the setting of the fuses is well adapted to the setting of the thermal relay (and / or thermal protection system), this to avoid the fusion of the thermal relay in the event of short-circuit.

This precaution is to be taken only if the thermal relay is directly connected.

If the thermal relay is connected with current transformers, the saturation of the current transformers protects the thermal relay.

Protection against short-circuits can also be done by magnetic relays. The principle of these relays is as follows:

When there is an overcurrent, the mobile frame (5) is attracted and close the circuit by the contacts (3) (4) what causes the trip of the contactor, when the overcurrent disappeared, the mobile frame (5) falls down.

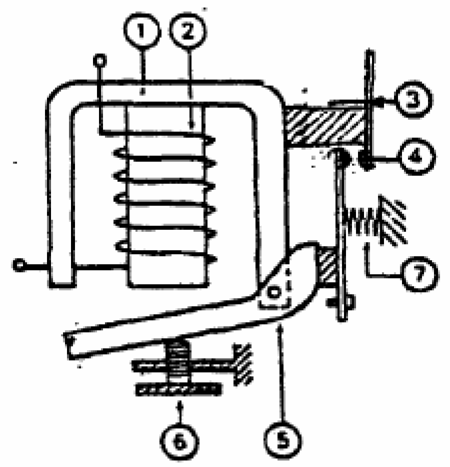


Figure 46: Basic design of a magnetic relay

Legend:
1 - Fixed magnetic circuit
2 - Large section of copper coil traversed by the overcurrent
3 - Fixed contact operating the contactor or the breaker
4 - Mobile contact
5 - Mobile magnetic circuit
6 - Adjustable screw of the air-gap to regulate the intensity of the release
7 - Return spring

This type of relay is to protect the circuits against the strong overcurrents, which need a fast opening of the contactor (or breaker).

These relays act instantaneously and especially in the event of short-circuit.

5.4.2.6. Earth faults (50N or 50G, 51N or 51G)

An earth fault is the most frequent fault occurring on rotating machines. Theses result from machine insulation damage, which allows a fault current to flow from the windings to earth via the stator laminations. The magnitude of this earth fault current depends on the network earthing arrangement (*see course MN-SE007 "Neutral and Ground Systems")*.

As in the case of phase-phase fault, a fast fault cleaning time is required in order to reduce damage and repair cost.

Whatever neutral earthing arrangement is used, the zero sequence unit built into the concerned relays, will provide adequate earth-fault protection. This unit may be connected either to a core-balanced CT (*residual current from a torus)* or used in the residual connection of the three line CT's. The core-balanced CT solution is the one we (always, nearly) choose whatever type of network earthing is used.

This protection is used to detect the ground fault. The protection is activated if the residual current Irsd = I1 + I2 + I3 exceed the threshold of the adjustment for a time equal to the selected temporisation.

In the absence of ground fault, the sum of the three currents of the three phases is always zero. The residual current gives the measurement of the current passing through the ground during the fault.

The protection can be independent or dependent time identically to the overcurrent phase protection (see figures and comments of the previous paragraph).

Measures of the residual current:

As said above, the measurement of the residual current can be obtained in two ways:

By a current transformer (torus type or core-balanced CT) including the three phases.

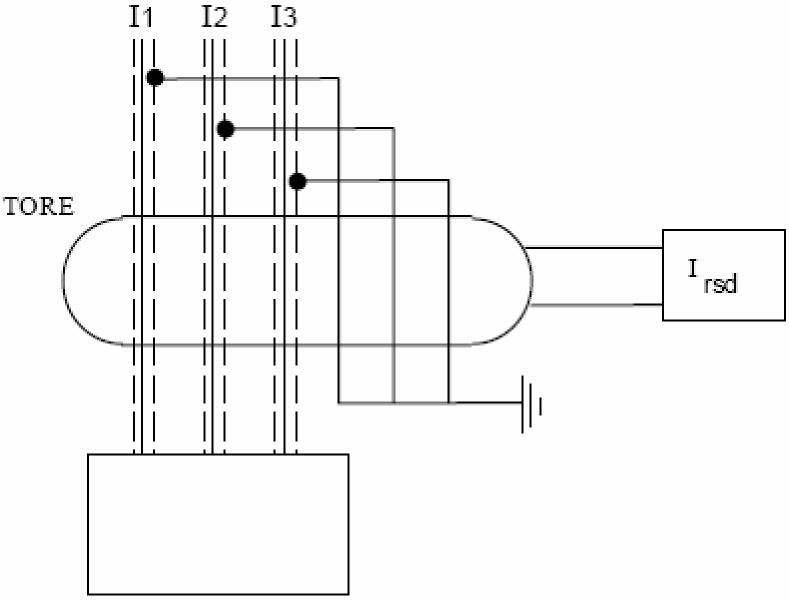


Figure 47: Measure of the residual current by a torus

The secondary windings of the current transformer have a magnetic flux

Φ rsd = Φ1 + Φ2 + Φ3

Φ1, Φ2 and Φ3 are proportional to the phase currents I1, I2 et I3, Φrsd is then proportional to the residual current.

The earthing braid of the screen cables as indicated on figure must pass inside the torus (***but not the earthing conductor***), so that an internal fault of the cable (phase screen) is detected. If not, the short-circuit current circulates in the core of the cable and comes back by the screen, it is thus not detected by the torus.

By three current transformers whose neutrals and phases are connected together (see figure).

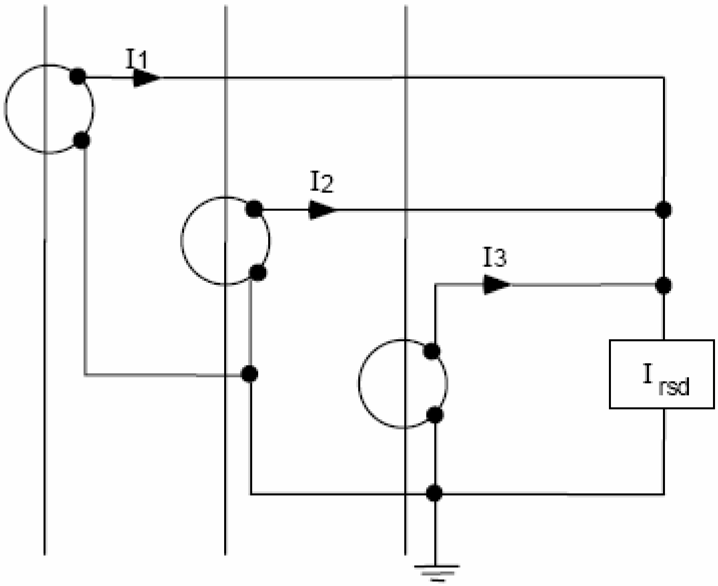


Figure 48: Measure of the residual current with three current transformers

Minimal threshold of the adjustment

There is a risk of a wrong activation of the protection due to an error of the residual current measurement, in particular in the presence of transient currents (at start, with unbalanced phase currents)

In order to avoid this risk, the threshold of the protection adjustment must be higher to:

- Approximately 12 % of the nominal of the current transformers when the measure is taken by three CT;
- 1 A with a temporisation of 0.1 s, when the measure is taken by a torus.

5.4.2.7. Start-up protections

Protection against excessive starting time, locked rotor and monitoring number of starts (code ANSI 48 / 51LR / 66)

The principle is based on an overcurrent protection with independent time (see course SE110 for information on “dependent / independent”

Too long start-up (code 48)

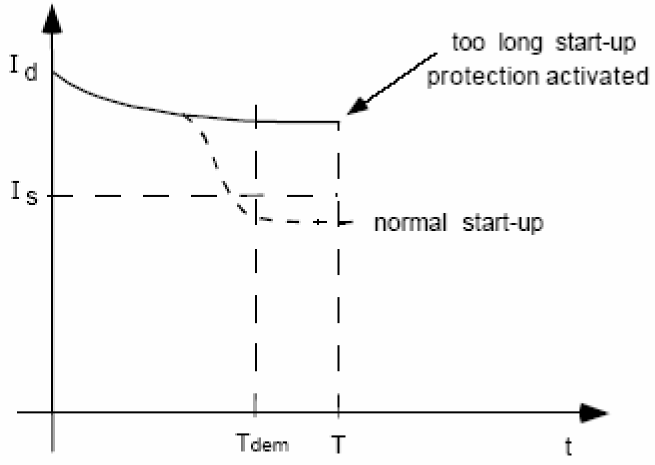


Figure 49: Inrush current of the motor with its associated starting system (Autotransformer, star - delta, electronic starter...) if existing.

During a start-up, the protection is activated if the current of one of the three phases is higher than the threshold of current Is during a time T (see figure).

This time T must be higher than the maximum value of the normal duration of Starting T_{start} (Td)

The start-up origin can be detected in two manners:

- By the closing of the breaker information
- When the current exceeds a low threshold (for example 5 % of In).

Rotor Locking (code 51LR)

During starting, the protection is locked.

In normal mode, the protection is activated if the current of one of the three phases is higher than the threshold current Is during a time higher than the temporisation Tb.

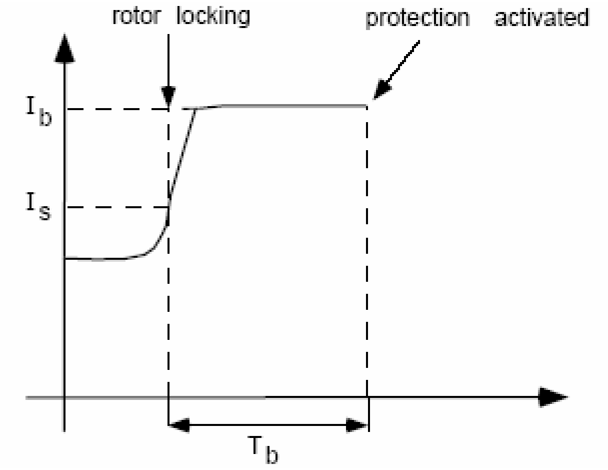


Figure 50: Case of a rotor locking

The figure shows the case of a rotor locking during a time higher than the temporisation.

The current with a rotor locking Ib is equal to the inrush current of the motor without the starting system. Indeed, the starting system is short-circuited after starting.

Monitoring number of starts (code 66)

Too many start-ups can be due to:

- A faulty operation of a control system
- A manual action too frequent
- A series of restart on a fault.

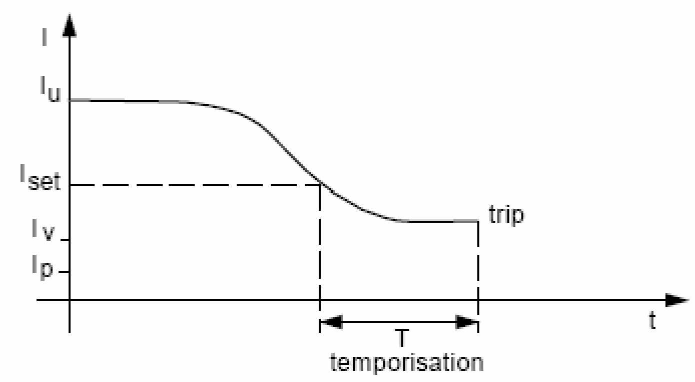
The consequences are:

- An overheating,
- A succession of shocks on the couplings.

A protection monitors the number of start-ups during a given time to protect the motor against too many start-ups, which may cause damage to the motor.

5.4.2.8. Undercurrent Protection – (Pump un-priming) - (37)

This undercurrent protection is used to detect the air binding of the pump or the breakdown of the coupling with the load. The suction pump air binding can be due to the absence of liquid in the pump.



The air binding of a pump or the breakdown of the coupling involve a no-load of the motor, therefore a drop of the current.

The undercurrent protection allows detecting the idle run of the motor.

Figure 51: Case of no-load motor

Iu : minimal current normally used by the user
Iv : no-load current
Ip : predetermined threshold for which the protection is inactive

Sometimes the current criteria may be not sufficient to detect pump un-priming. In these cases the use of an under – power (active) relay is suggested.

5.4.2.9. Undervoltage (27)

The voltage drop can be due to:

- An overload for a network supplied with generators,
- A faulty operation of a transformer load taps changer or a voltage regulator of a generator

The consequences are an overheating of the motors:

- At the start-up, the starting torque and the maximum torque are proportional to the square of the voltage. A voltage drop involves a longer start-up time, therefore a overheating, and if the resistive torque is more important than the maximum torque, a rotor locking.
- In normal operation, the active power of the motor is: $Pa = \sqrt{3}.U.I.\cos\varphi$
  If the voltage drops, the load being constant, the current increases in order to maintain the motor output (the value of the cos φ almost do not change). Thus, for voltage variations which are not too important, we have: $Pa = \sqrt{3}.U.I.\cos\varphi$ = constant; the Joule losses are equal to 3 RI^2 and thus the heating increases.

The under voltage protection allows protecting the motors against a voltage drop, which may deteriorate them by overheating.

The undervoltage protection can be used also to:

- control the operation of the voltage regulators,
- load shedding the non priority consumers during an overload,
- control the voltage before the permutation of power supply.

5.4.2.10. Other protections for motors

Other protections such as overvoltage (59), mini and maxi frequency (81), ….etc, are complementary protections which can be used specifically in motor protection.

Nevertheless, they are generally “network protection” and therefore are detailed in course SE 110 for “electrical protections”.

5.4.2.11. Special Protection for Synchronous Motors

Synchronous motor protection schemes tend to use most of the above relays, nevertheless some additional protection must be considered

Synchronous Motor is also a generator; same protections consequently exist for generators. We just enumerate them here and for more details see the course MN-SE060 “electrical power generation’”

- Loss of Field (40)
- Loss of Synchronism (55)
- Rotor Earth fault protection (64F)
- …/…

6. COMMON MOTOR STARTERS

6.1. DIRECT START

6.1.1. DOL Starter

Starting Current

When the stator winding of the induction motor is energised, with the rotor at a standstill, the slip is 100% and therefore maximum emf is induced in the rotor. Since the resistance of the squirrel cage rotor is very low a heavy current will flow through it, this current produces a magnetic flux, which opposes and therefore weakens the stator flux. The current in the stator windings is limited by self induced emf which opposes the supply; the weakening action of the rotor flux reduces this self induced emf causing heavy current to be taken by the stator winding.

The direct – on line starter (DOL) is one of the most common starters to be found, it gets its name due to the fact that the motor is connected direct to the supply via a contactor. It can be seen that when it is connected to the supply there will be an initial current surge typically this is in the region of six to eight times motor full load current.

An industrial machine will however develop somewhere in the region of 170% torque on start – up making it suitable for drives where loads are directly connected from the instant of start. The supply equipment (transformers, cables etc.) must be of adequate capacity to withstand the heavy starting current otherwise this initial surge of current can cause voltage drops, which can effect the correct functioning of other equipment.

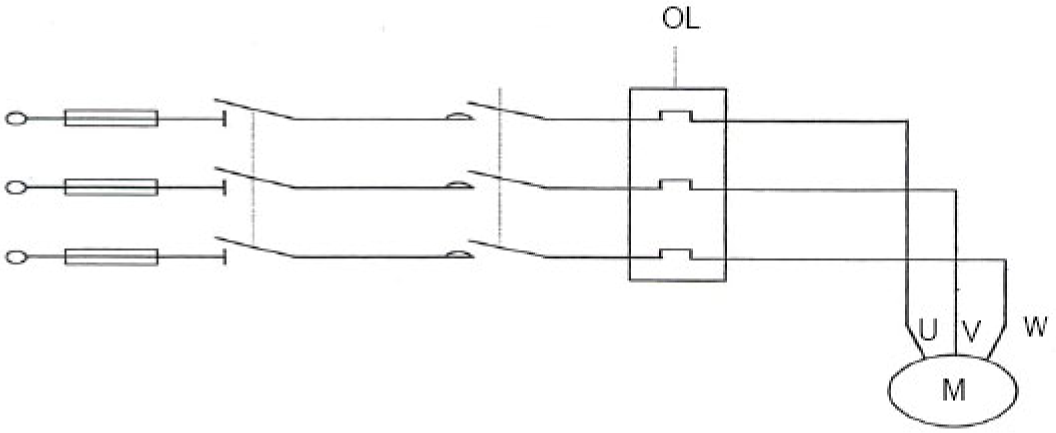
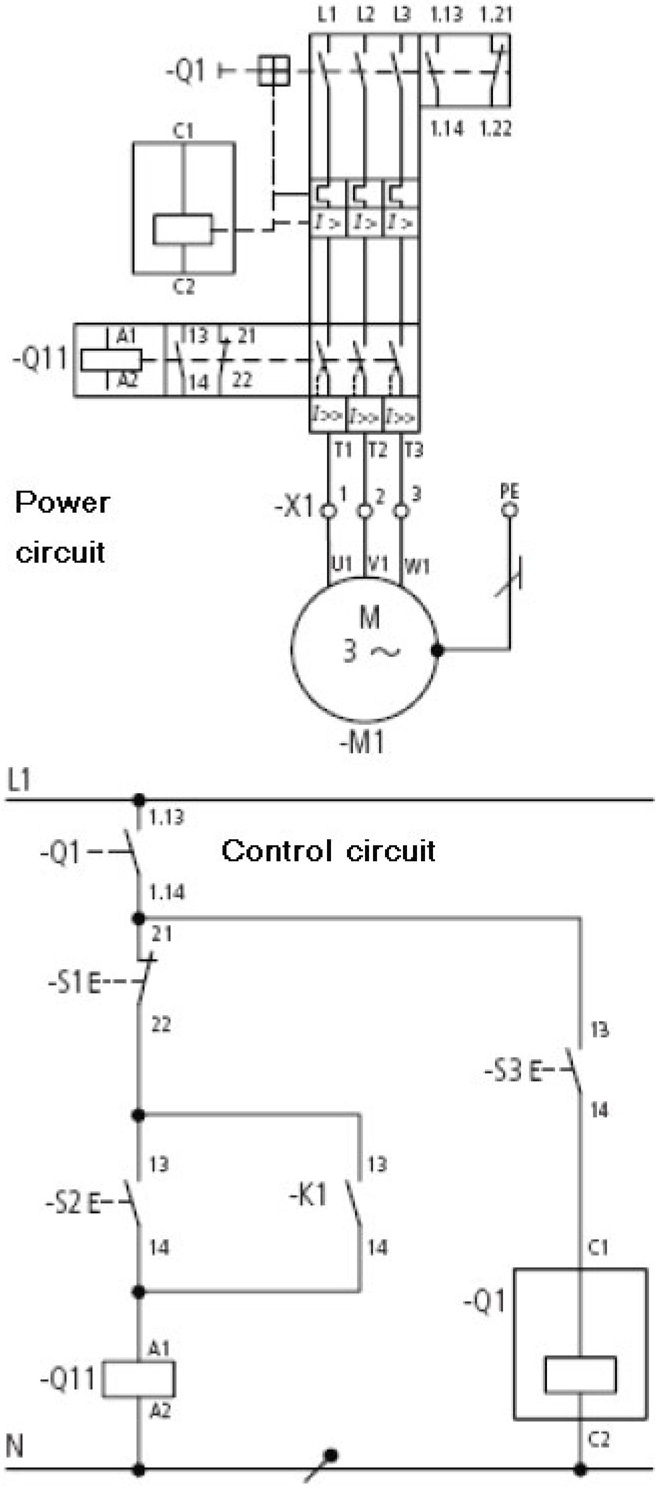


Figure 52: Typical Direct On Line motor Starter

This is the minimum, “old fashion” starting system, with fuse, contactor, and thermal relay, already seen previously. Concerning more “sophisticated” power and control schematics, let us see hereafter.

6.1.2. Protection by motor-breaker

We consider, protection by a breaker equipped with an additional device: a tripping coil (Mx type = voltage present for action), and start of motor by a contactor



Legend:

Q1: motor-breaker
Q11: contactor
C (C1, C2): tripping coil Mx
S1: Stop push button
S2: On push button
S3: Emergency stop push button (or any contact from a tripping device

Note also the numbering principle used for the contacts and represented on schematics, power and control

Figure 53: Direct start protection by motor-breaker

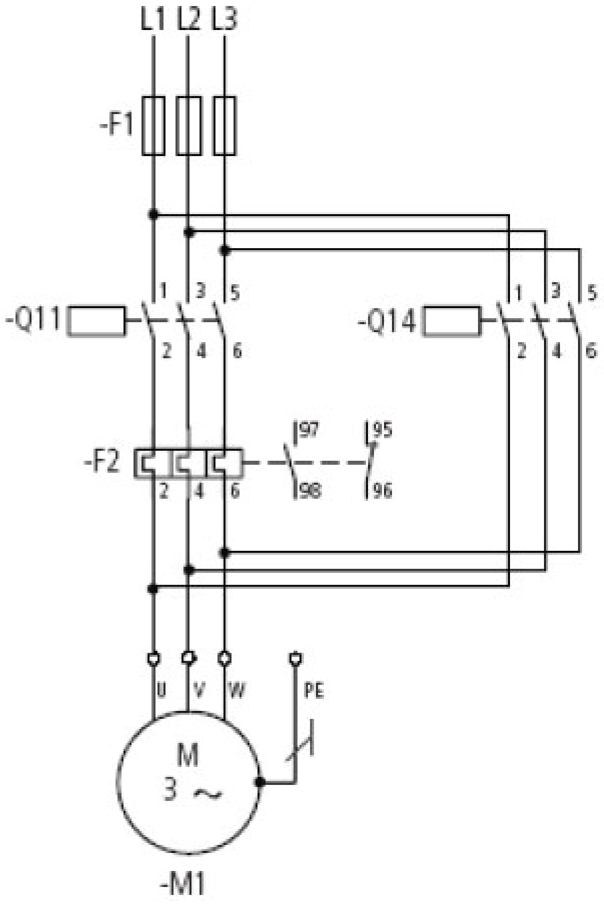
Breaker Q1 is manually operated for closing power circuit and enabling control through contact (1.13 – 1.14)

Contactor Q11 is powered “on” or “off” with the “on” and “stop” push-button, self maintained by the auxiliary relay contact K1 (13 – 14). *(Relay K1 non represented)*

Action on S3 energises the coil C (C1 – C2) which through mechanical link, in parallel with the thermal and magnetic trips, forces the breaker Q1 in open position.

A manual intervention will be necessary to switch back “on” the breaker Q1

6.1.3. Thermal Protection with by pass at start



Let us go back to the typical start: fuses + contactor + thermal relay, but as we are in the case or a "long start", we need to by-pass the thermal relay

Figure 54: Direct motor start with by-pass of thermal relay – power circuit

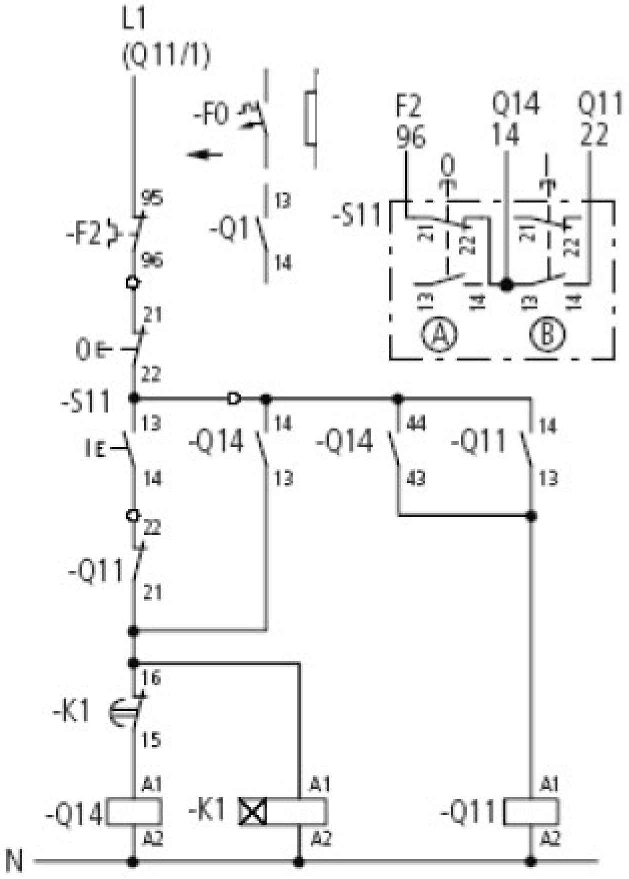


Figure 55: Direct motor start with by-pass of thermal relay – control circuit

Legend

Q11: Line contactor
Q14: By-pass contactor
K1: Time delay relay
S11: Push-button box with "0"= stop and "I" = on

Operation

Action on push-button "I" energise by-pass relay/contactor Q14 which is self-maintained by contact Q14 (13-14); Time delay relay K1 is simultaneously energised. Line contactor is called by contact Q14 (44-43) and is self-maintained by contact Q11 (14-13). At end of delay, function of starting period of motor, by-pass contactor is de-energised by contact K1 (16-15). K1 is powered off as well and like Q14 is ready for re-energising after stop though push-button "0". The normally closed contact Q11 (22-21) prevents the re-energising of Q14 and K1 in normal running. In case of (thermal) overload, break is operated by the normally closed contact F2 (95-96).

6.1.4. Starter two rotations directions

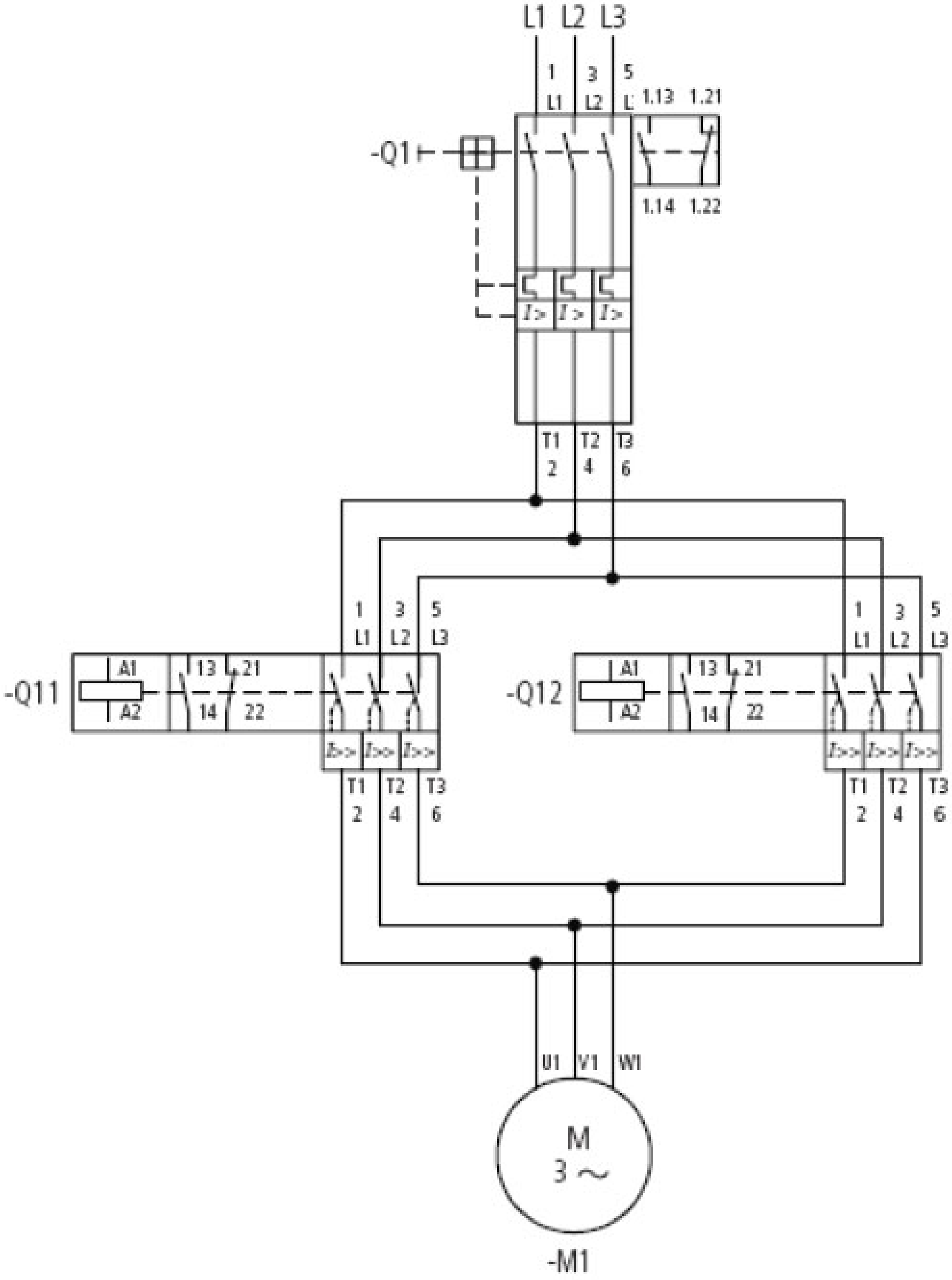


Figure 56: Direct start – two rotations directions – power circuit

We still use here the motor-breaker as unique protection, but we need (of course) two contactors for the two conditions of rotations

Let us see the control circuit

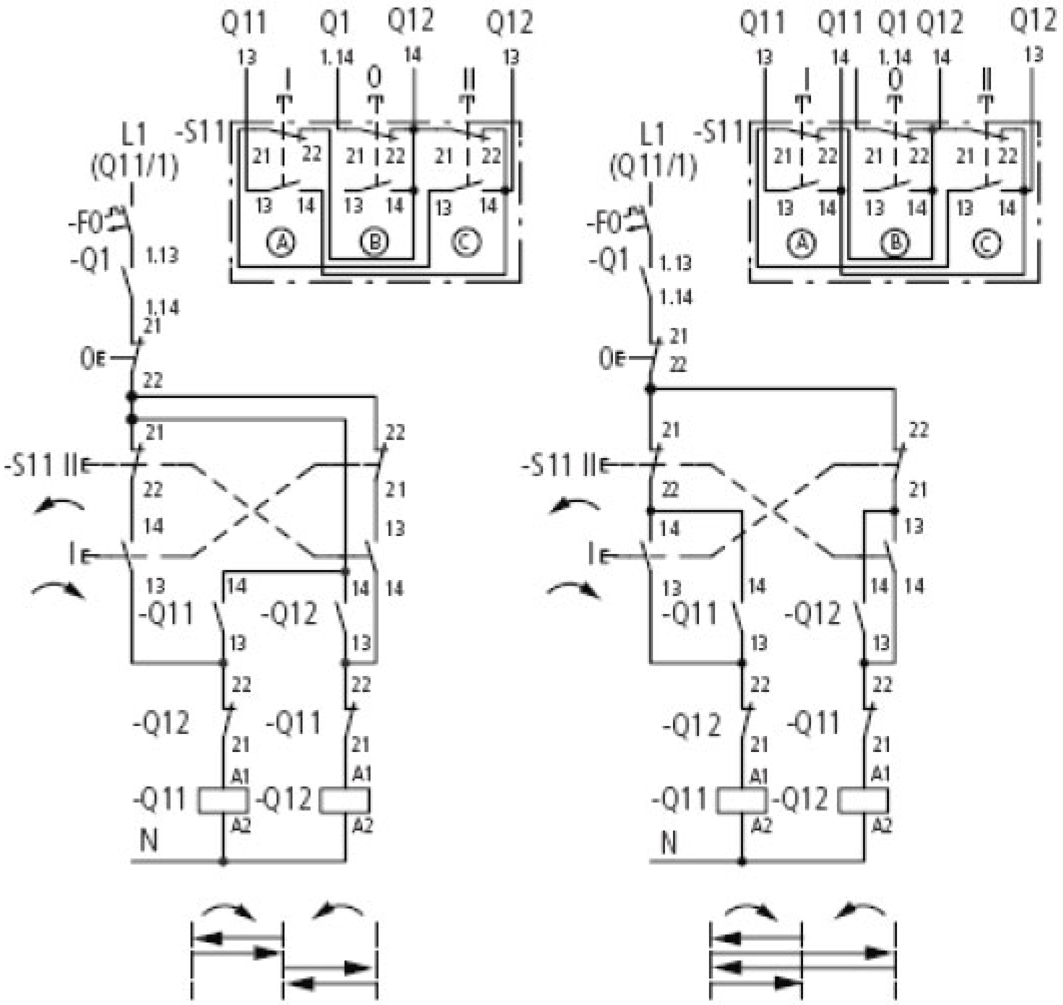


Figure 57: Direct start – two rotations directions – control circuit

Legend:
Q1: general protection breaker
Q11 & **Q12**: one rotation direction contactor
S11: push button box with 3 buttons: **'0'** = stop - **'I'** = one direction - **'II'** = second direction
F0: optional contact (non on power circuit), which could be auxiliary contact of an isolator (with fuses), or an auxiliary contact from a fuse blown, or any contact from an interlock sequence

The control circuit represent two possibilities of wiring, with the simplest way using electrical interlock between the two contactors. Mechanical interlock could as well equip the two contactors.

Note that with the motor-breaker, there is no (obligatory) need to use a trip auxiliary contact in the control circuit, but you can always add a "breaker trip" contact being actuated by the mechanical link of thermal-magnetic protection of the breaker; In the present configuration, once the breaker has been (mechanically) tripped, the auxiliary contact Q (1.13 – 1.14) opens the control circuit.

What are the difference between the left and the right control circuit schematics?

The difference is represented by the “arrows” at bottom of the two possibilities of connections

At left, you need to push the stop button prior to go on the other direction.

At right, you can go directly one way or other by using only the “I” et “II” buttons

In both cases, the timing between the possibilities of going from one direction to the other one is only function of the relays/contactors opening/closing delay. It means that the motor is requested to reverse when still running one way; motor and protections have to be adapted for.

6.1.5. Direct start – Dahlander connection – two speed + two rotation directions

Let see back the Dahlander connections seen in course EXP-PR-EQ150, chapter 12

6.1.5.1. Motors with pole coupling (operators course)

It is possible to obtain a motor with two or more speeds by creating combinations of coils corresponding to different numbers of poles in the stator.

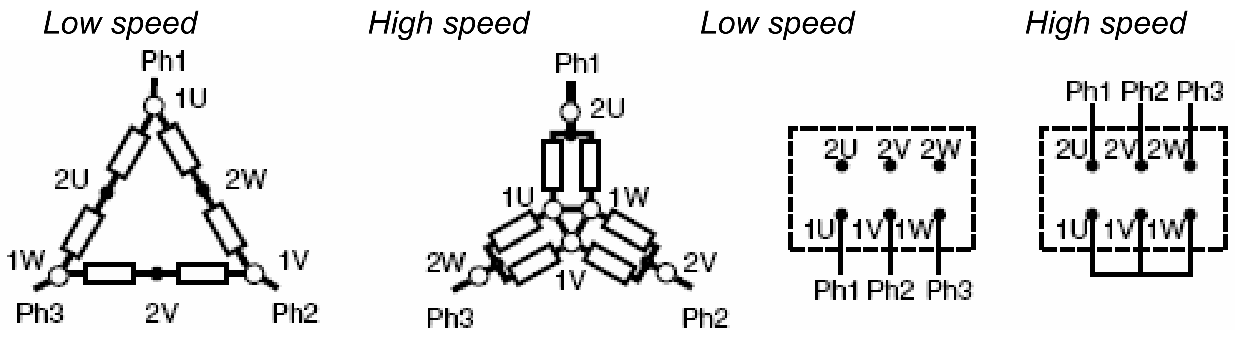


Figure 58: Dahlander delta/wye coupling (constant torque)

This type of motor only allows for speed ratios of 1 to 2 (4 and 8 poles, 6 and 12 poles, etc.). It includes six terminals.

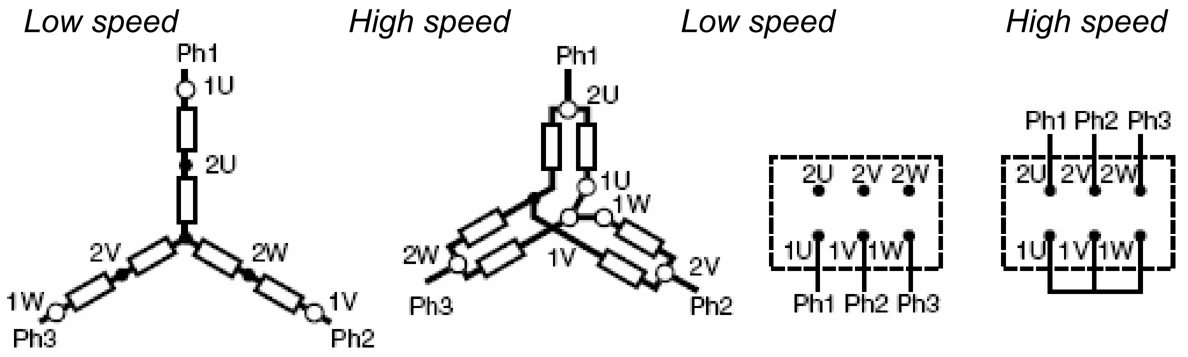

Low speed High speed Low speed High speed

Figure 59: Dahlander wye/wye-wye coupling (quadratic torque)

The network is connected to the three corresponding terminals for one of the speeds. The terminals are interconnected for a second speed and the network is connected to the three other terminals.

6.1.5.2. Control diagram for Dahlander coupling + rotation reversing

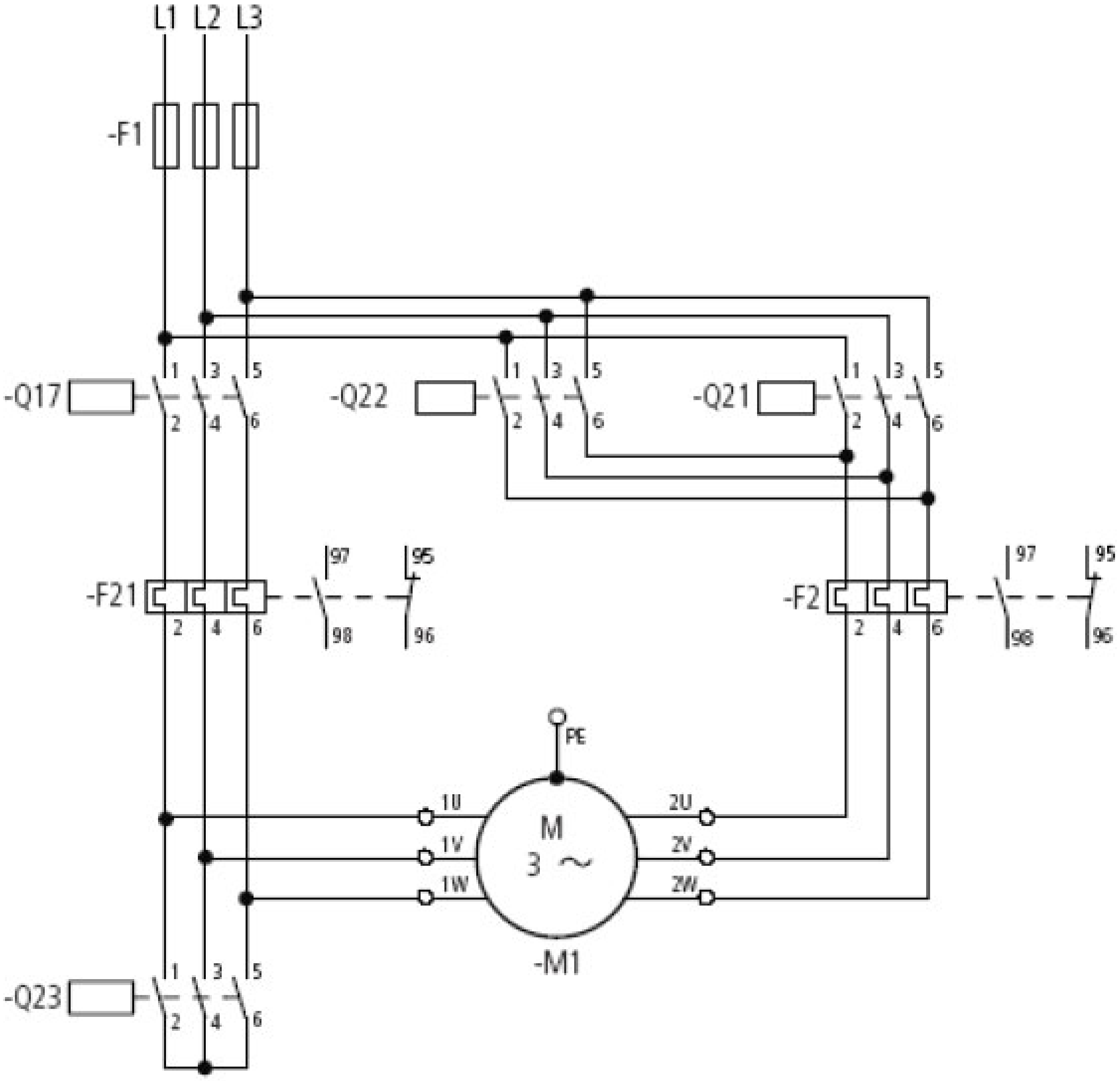


Figure 60: Direct start – two speed – two rotation directions – Dahlander coupling – power circuit

Note: Forward: Low speed + high speed
Reverse: High speed only

Legend

Q17: Low speed forward **Q21:** High speed forward **Q23**: star connection contactor
Q22: High speed reverse **K1**: auxiliary relay
Push-button box: **0:** stop **I:** Low speed forward (Q17)
II: High speed forward (Q21 + Q23) **III:** High speed reverse (Q22 + Q23)

Operation:

Forward is initiated by action on push-button either “I” or “II” as per the required speed.

Push-button “I’ start the sequence through Q17 (or energises Q17) which is self-maintained by its contact Q17 (13 – 14). Then to go in high speed, action on push-button “II” de-energises Q17 (closing back the NC Q17 (21 – 22) and energises the star contactor Q23 which in turn energises the high speed contactor Q21 through its Normally Open contact Q23 (13 – 14). In this operation, we can proceed from forward high speed, back to forward Low speed by depressing again push-button “I” *(and so on, “I”, “II”, “I”,….indefinitely)*

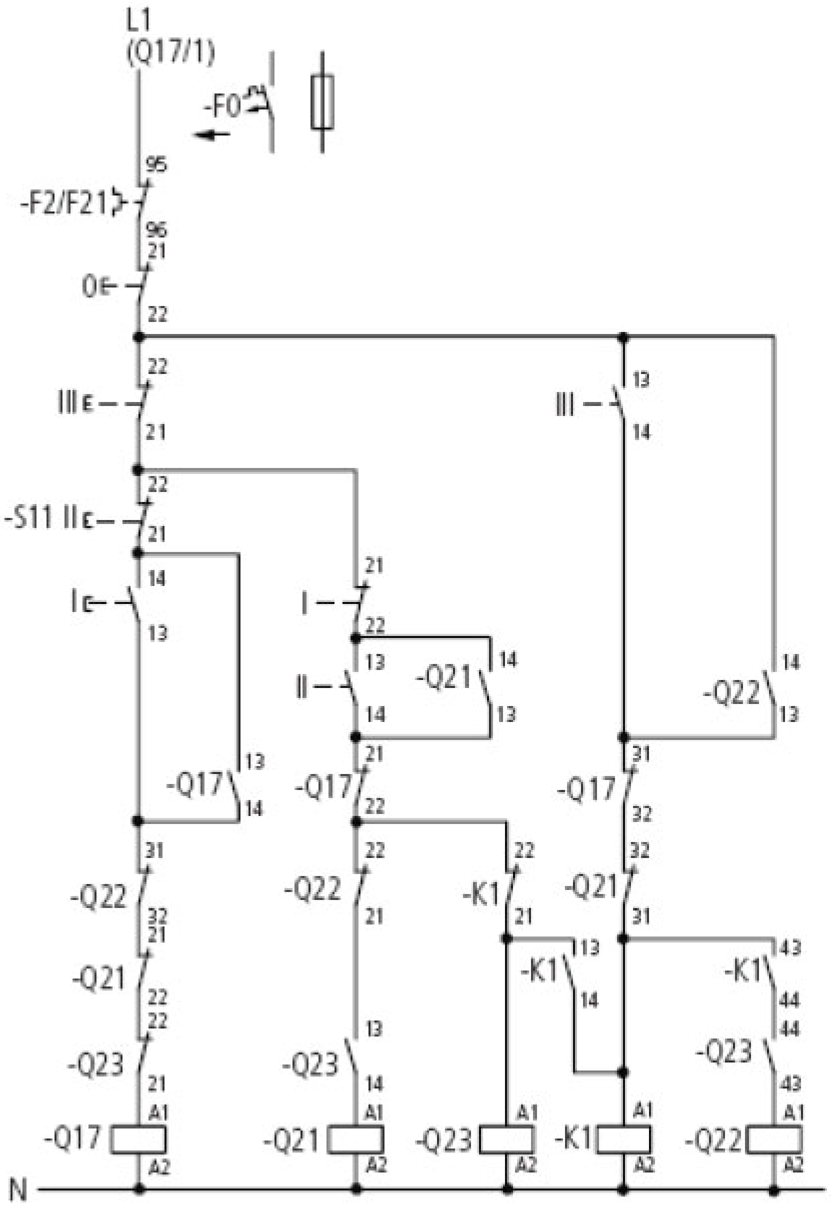


Figure 61: Direct start – two speed – two rotation directions – Dahlander coupling – control circuit

To go in reverse (high speed), the motor has to be stopped from going in forward. The contact NC Q17 (31 – 32) for forward low speed and contact NC Q21 (31 – 32) providing the electrical interlock.

Initiation of reverse high speed is done by action on push-button “III”. Auxiliary relay K1 is called, and energises in turn the star contactor Q23 trough NO contact K1 (13 – 14). The High speed (reverse) contactor Q22 is in turn energised via NO contacts K1 (43 – 44) and Q23 (44 – 43). Self-maintain via Q22 (14 – 13). Only the stop push-button “0” can stop this sequence, no other actions on the push-buttons are operational.

6.2. STAR DELTA START

6.2.1. Generalities Star-Delta

Already seen in the operator course EXP-MN-EQ150, if you are electrician, you have seen it at school or at work, bur nevertheless, I am sure, that if I request you to write, right away the control drawing of this system, you will need to think a (little bit…) about it. So, let's see it again…, this is the standard, "unavoidable" principle in motor starter.

The star-delta starter is used when it is necessary to reduce the starting current taken when starting direct–on–line. This method of starting firstly connects the motor in star then once up to speed changes it over to delta. By doing this the starting current is reduced to one third of that taken when starting DOL, i.e. it takes approximately twice full load current instead of six times FLC.

As there is such a reduction in starting current it follows that there must be a reduction in starting torque, this is about 50% full load torque on start – up, it is therefore unsuitable for drives which require more than this. It is used for fans, pumps, machine tools compressors etc, with fans and pumps they do not offer a great deal of load to the motor until they are going at some speed, machine tools are not used to cut until up to speed, compressors can be started off load.

Current on start – up:

When connected in star, the phase voltage is the line voltage ÷ √ 3 which works out at 58% of line voltage, i.e.

$$VP = VL / \sqrt{3}$$

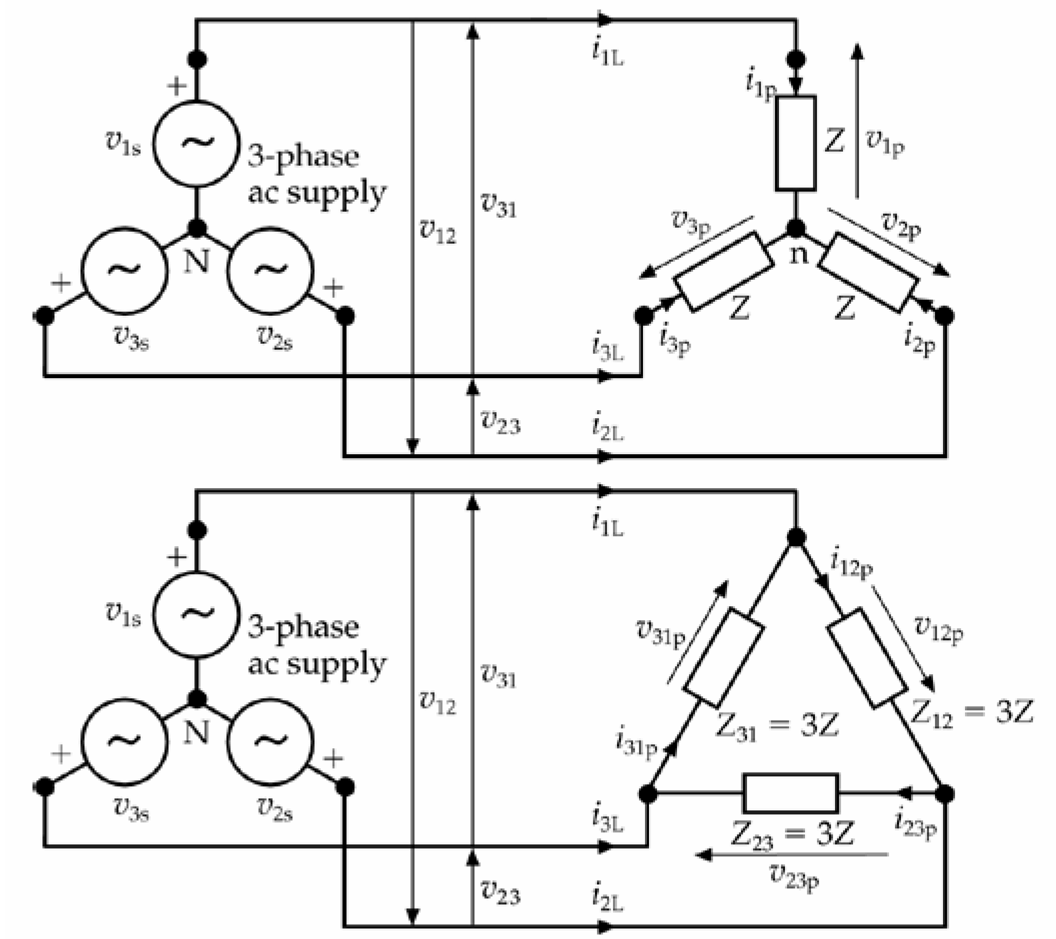
The current in star is 1/3 of delta line current.

Example:

A 400V squirrel cage motor takes 200amps when started in delta (i.e. DOL).
How much current would it take when started in star?

The phase impedance Z. is the same in both cases

See also course EXP-MN-SE020 "main formulas in electricity", in chapter 4 showing the "equivalency" between resistance in star and in delta



Star		**Delta**
Phase Current	$I_{1P} = I_{1L}$, $I_{2P} = I_{2L}$, etc	$I_P = I_L / \sqrt{3}$
Line Current	$I_L = I_{1L} = I_{2L} = I_{3L}$ …	$I_L = I_{1L} = I_{2L} = I_{3L}$… $I_P = I_{12P} = I_{23P} = I_{31P}$
Phase Voltage	$V_P = V_L / \sqrt{3}$	$V_{12} = V_{12P}$, $V_{23} = V_{23P}$, $V_{31} = V_{31P}$
Line Voltage	$V_L = V_{12} = V_{23} = V_{31}$	$V_L = V_{12} = V_{23} = V_{31}$ and $V_P = V_{1P} = V_{2P} = V_{3P}$ …

Figure 62: Differences between delta and star connections

Therefore (for our ***motor*** 400V – 200A ***in Delta***):

$$Z = .\frac{Vp}{Ip}. = .\frac{V_L}{(I_L/\sqrt{3})}. = .\frac{400}{(200/\sqrt{3})}. = .2.x.\sqrt{3}.\Omega.$$ phase impedance of this motor

Note

The information used for this is that provided for delta i.e. line volts = phase volts

Phase current = line current ÷ √ 3

Motor Current in star

$$Ip. = .I_L = \frac{Vp}{Z}. = .\frac{\frac{V_L}{\sqrt{3}}}{Z}. = .\frac{\frac{V_L}{\sqrt{3}}}{2.x.\sqrt{3}}. = .\frac{V_L}{\sqrt{3}}.x.\frac{1}{2.x.\sqrt{3}}. = .\frac{V_L}{3.x.2}. = .\frac{400}{6} = 66,6.Amp$$

As can be seen the current taken in star is one third that which was being taken when connected in delta.

6.2.2. Protections possibilities in Star-Delta

Only one thermal relay is sufficient to protect the motor but there are 3 possibilities of connecting it with a good reason for each possibility to be used! Let us see these 3 starting protection methods function of motor starting time

Protection for a Star-Delta starter, one rotation direction, as per position of thermal relay and starting time in position Star (wye).

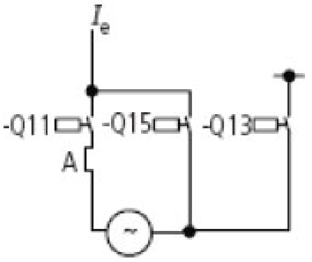
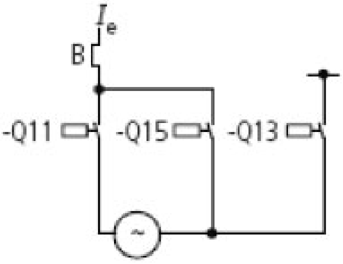
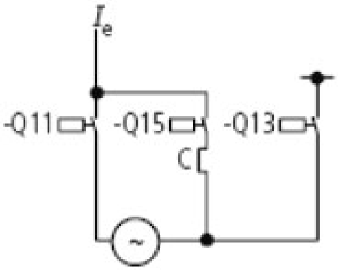
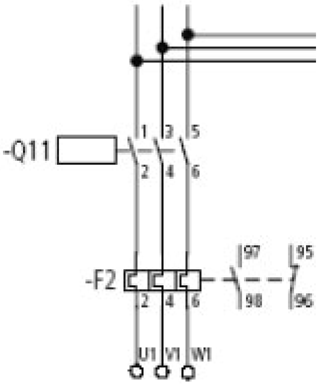
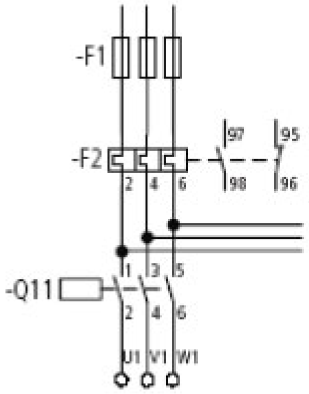
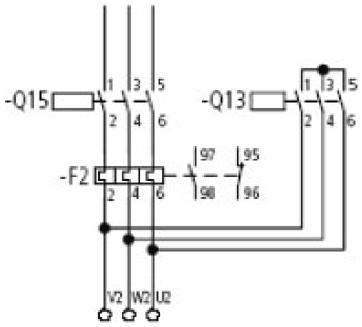
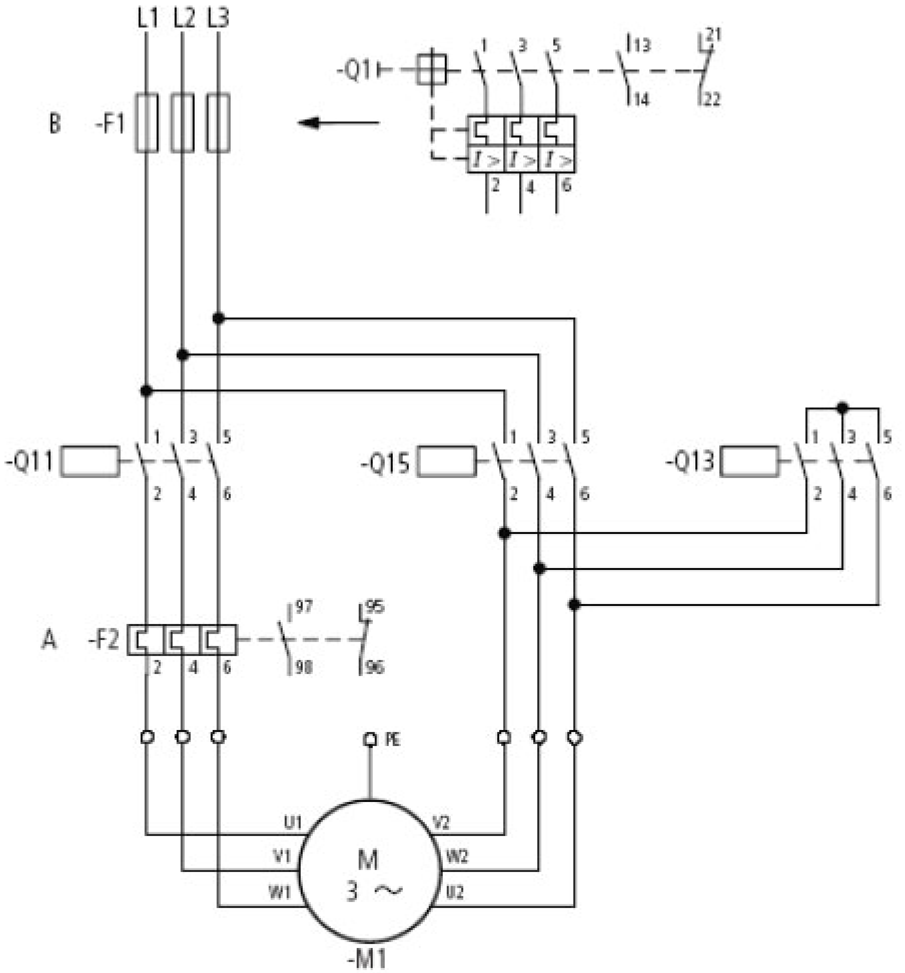
Time for commutation Y to Δ	**A: < 15 s**	**B: > 15 < 40 s**	**C: > 40 s**
Position of thermal relay General one line drawing			
Position of thermal relay Power circuit detail		 -F1 -F2 97 95 98 96 2 4 6 -Q11 1 3 5 2 4 6 U1 V1 W1	 -Q15 1 3 5 2 4 6 -Q13 1 3 5 2 4 6 -F2 97 95 98 96 V2 W2 U2
Adjustment of thermal relay	0.58 x In	1 x In	0.58 x In
General comment	Complete motor protection in Delta and Star	Limited protection in Star position	No protection in Star position, only in Delta
Comments	With thermal relay in the "line contactor" circuit, protection is efficient in Y and Δ as in both cases, the thermal relay in series with the windings is crossed by the phase current which is 0.58 times the nominal motor current	With thermal relay in the "supply line" circuit, set of relay has to be as per the nominal motor current. This setpoint is then 1.73 times the phase current, and the current in Star position. But this protection is efficient in case of immediate restart	With thermal relay in the "delta contactor line" circuit, the motor has to be "long start time" type (as per centrifuge machine for example). No protection in Star, but as the start period is long (and difficult), a relay in the star branch could find this time too long also….

Table 11: Different thermal protection possibilities with a Star-Delta starter

6.2.3. Schematic –typical Star-Delta



General protection either by fuses or thermo magnetic breaker

Mounting and rating of material and protections:

Position A (Star) as F2 is under Q11 (Time < 15 s)

Set F2 = 0.58 In *(multiplied by 1,05 to 1,15 if overload is authorised)*

Q11, Q15 = 0.58 In
Q13 = 0.33 In

Figure 63: Starter "Star-Delta – power circuit

Legend:

Q11: Line contactor
Q13: Star contactor
Q15: Delta contactor
K1: Time delay relay (10 s): delay on coil + additional timed contact (0.1 s)
Control box: "I": on "0": stop
Control circuit represented with 2 possibilities: actuation by push-buttons (S11) or by switches (S14)

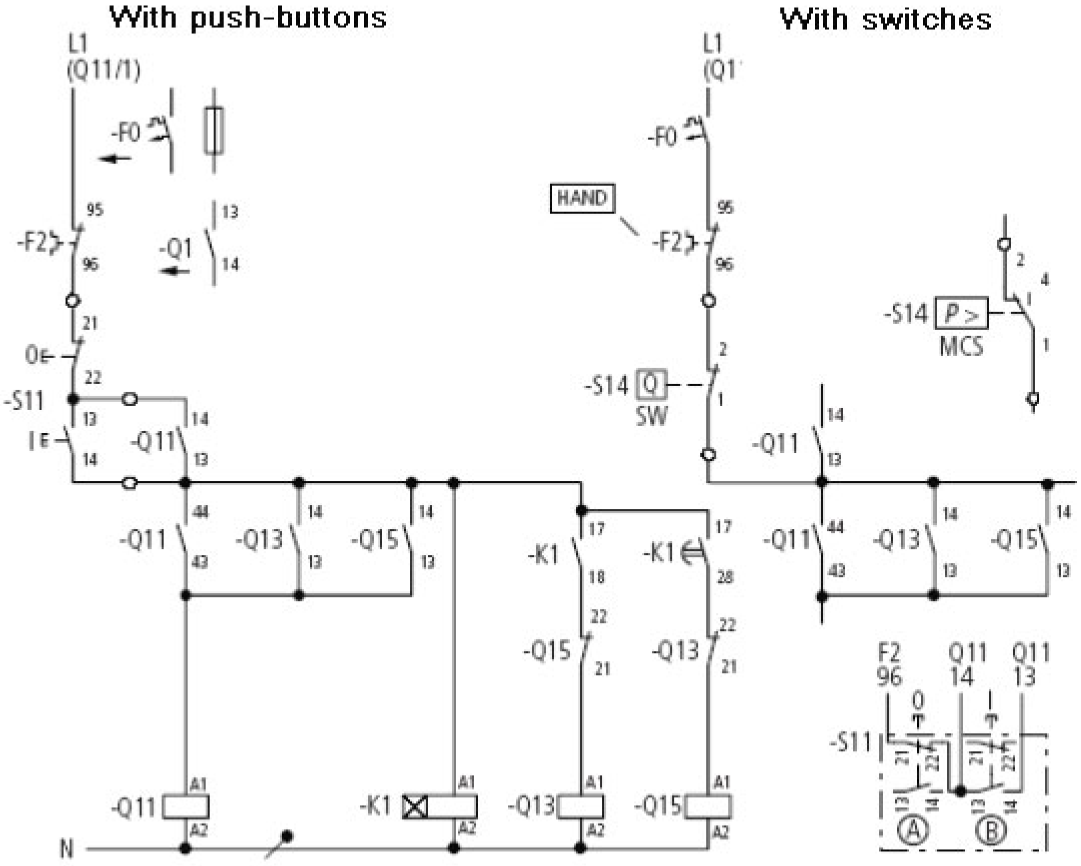


Figure 64: Starter “Star-Delta – control circuit solution 1

Operation:

Push-button “I” energises K1, its NO instant contact K1 (17 – 18) energises the star contactor Q13. Q13, being energised, in turn supplies Q11 through NO contact Q13 (14 – 13). Q11 and Q13 are self maintained by NO contacts Q11 (14 – 13) and Q11 (44 – 43). In same time, time delay contact K1 (17 – 28), slightly timed, has closed but contact NC Q13 (22 – 21) being already opened lock the energising of Q15. *(Contact K1 (17 – 18) should represented closed for NC to avoid confusion – as in delta / star / reverse scheme in the following)*

Motor is under power in star configuration.

At end of coil timing of K1, contact K1 (17 – 18) opens circuit of Q13. Q13 being de-energised (re)close its contact Q13 (22 – 21) allowing Q15 to be called on.
Motor is coupled in Delta configuration.
Simultaneously, contact NC, Q15 (22 – 21) opens, interrupting the possibility of going back in star. This is an electrical interlock; however star-delta contactors are generally equipped with a complementary mechanical interlock
A new start sequence is only feasible after stop via push-button “0” or F2 (95 – 96) and also the fuse blown contact F0 (in case of fuse protection) and/or the breaker contact Q1 (13 – 14) (in case of protection by breaker).

Other solution in control circuit:

With K1, being a “normal” relay equipped with a time delay contact

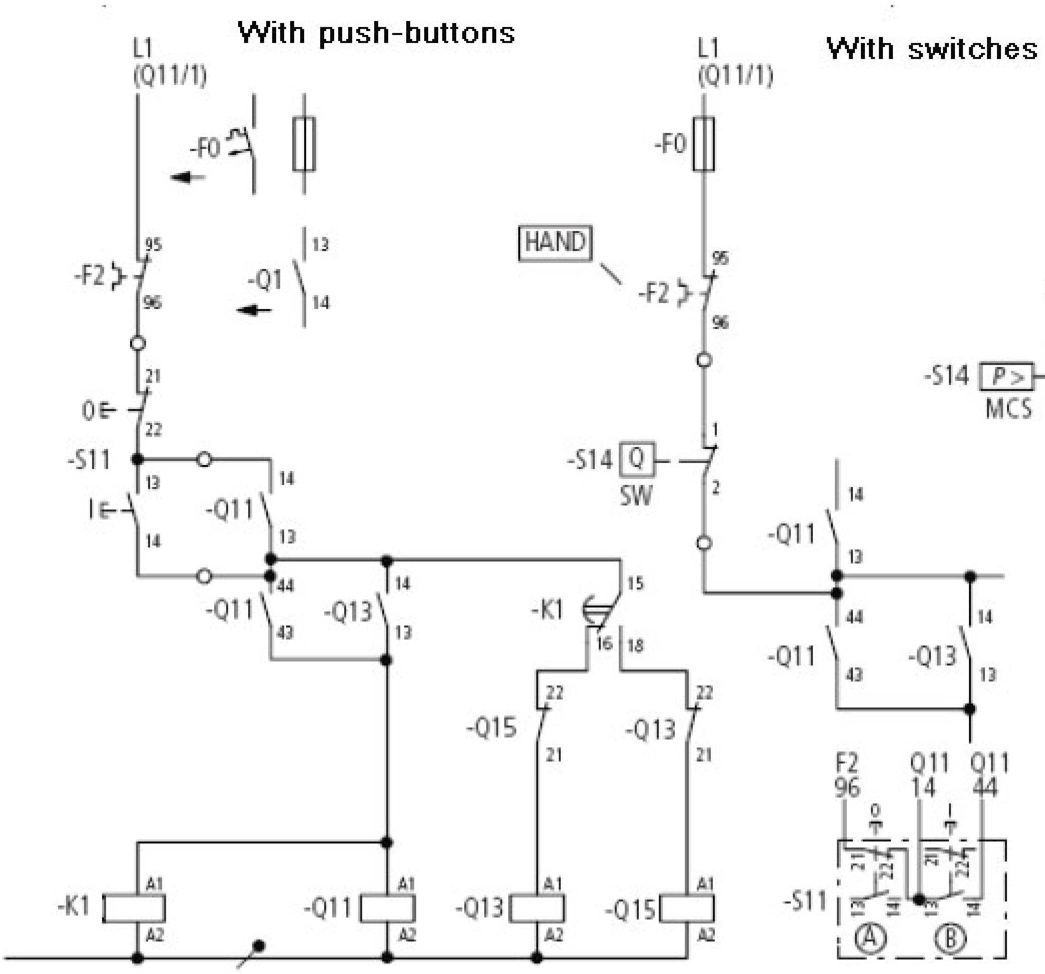


Figure 65: Starter “Star-Delta – control circuit solution 2

Operation:

Push-button “I” energises the star contactor Q13 (through NC contact K1 (15 – 16). Q13, being energised, in turn supplies Q11 through NO contact Q13 (14 – 13). Q11 is self maintained by NO contacts Q11 (14 – 13) and Q11 (44 – 43). Simultaneously, time delay relay K1 has closed, starting the delay timing and contact NC Q13 (22 – 21) having opened lock the energising of Q15
Motor is under power in star configuration.
At end of (contact) time delay, contact K1 (15 – 16) open, de-energising Q13 and (in the same “movement”, K1 closes its contact K1 (15 – 16) energising Q15, the contact Q13 (22 – 21) being gone to its NC position. Contactor delta being called, Q11 being kept on line, the motor is running in Delta configuration. Simultaneously, contact NC, Q15 (22 – 21) opens, interrupting the possibility of going back in star.
Stop as per the previous sequence.

6.2.4. Schematic Star-Delta and two rotation direction

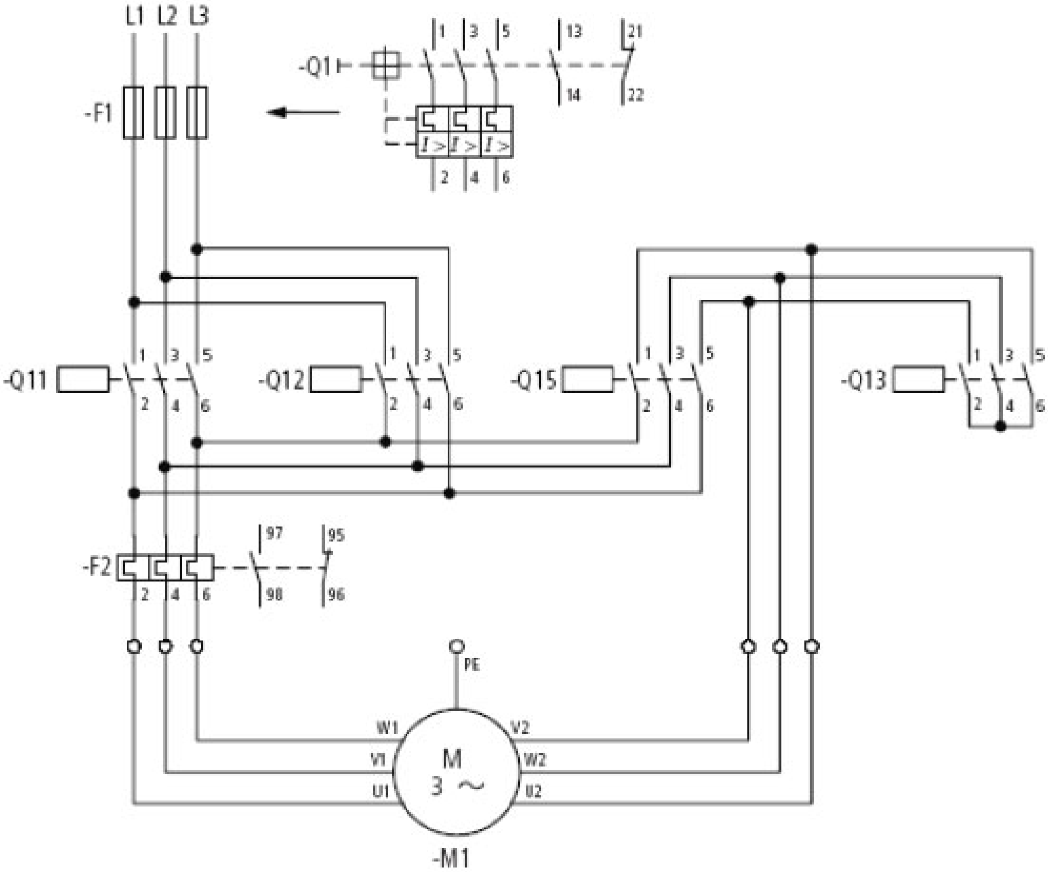


Figure 66: Starter “Star-Delta + reverse rotation – power circuit

General protection either by fuses or thermo magnetic breaker

Mounting and rating of material and protections:

Position A (Star) as F2 is under Q11 / Q12 (Time < 15 s)
Set F2 = 0.58 In. *(multiplied by 1,05 to 1,15 if overload is authorised)*
Q11, Q12 = In Q15 = 0.58 In Q13 = 0.33 In

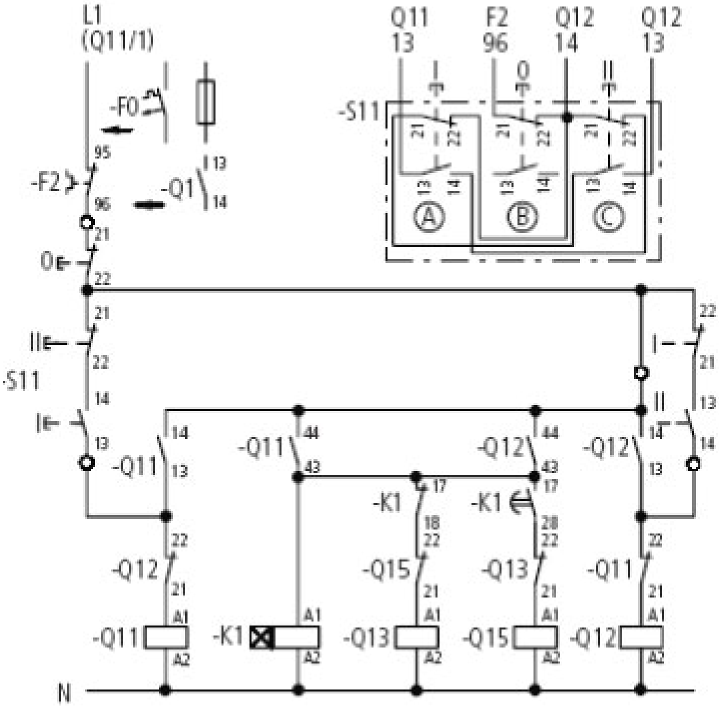


Figure 67: Starter “Star-Delta + reverse rotation – control circuit – reverse after action on “0”

Legend:

Q11, Q12: Line contactor
Q13: Star contactor
Q15: Delta contactor
K1: Time delay relay (10 s): delay on coil

+ additional timed contact (0.1 s)
Control box with 3 push-buttons: “I”: right “0”: stop “II”: left

2 possibilities of operation:

- Going directly from left to right (or right to left) without action on “0”
- Action on stop button “0”, prior reversing the rotation

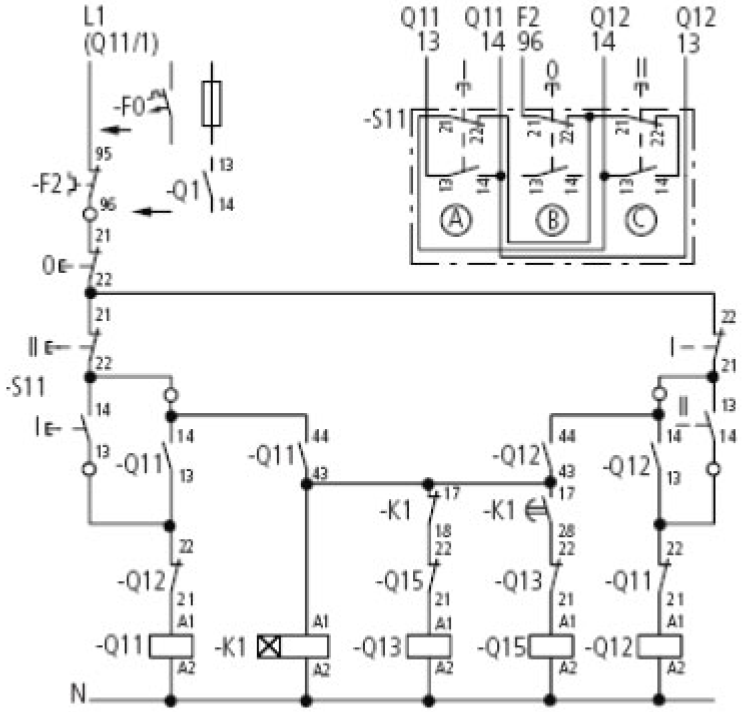


Figure 68: Starter “Star-Delta + reverse rotation – control circuit – reverse without action on “0”

Operation:

Push-button “I” actuates Q11 (left)
Push-button “II” actuates Q12 (right)

The called contactor is self-maintained by its own contact (14 – 13) and through push-button “0”. The contact (44 – 43) of each line contactor supplies star contactor Q13. Motor is starting in star configuration. Contact Q13 (22 – 21) opens avoiding delta contactor Q15 closing (contact K1 (17 – 28 being still open).

Simultaneously Time delay relay K1 is called starting (coil) timing count for contact NC K1 (17 – 18), Contact NO K1 (17 – 28) is slightly times (1 s) to allow the interlock Q13 (22 – 21) to be “operational.
At end of timing , contact K1 (17 – 18) opens, and stays opened as K1 is still activated, cutting power to Q13 which de-energises. Its contact Q13 (22 – 21) goes back to its NC condition; K1 (17 – 28) being closed, Q15 is energised. Contact Q15 22 – 21) locks the re-activation of Q13
Motor is running in delta configuration
To inverse direction, according to type of scheme either depress the “0” pushbutton passing by the stop conditions, or, depress directly the opposite direction push-button.
Thermal / fuse / breaker interlocks as per previous schematics.

Other types of starting systems could be seen, but this course is on “motors” not on schematics……

For motors starters equipped with frequency / speed “variators”, see course EXP-MN-SE120, “Distribution panels”, a speed / frequency regulator is always part of a panel…

7. MOTOR TESTING

The testing of electrical machines can be highly specialized task requiring specialist knowledge and equipment. The maintenance engineer in the field however needs to be able to carry out preliminary fault finding procedures if costly down time and necessary work are to be avoided.

We will look at some of the fundamental electrical faults, which can arise in motors and the tests, which should be carried out as a matter of course on any machine before installation is carried out, or applying power to a new or replacement motor, it is crucial that its electrical integrity is verified.

Note
Before any tests are carried out on a machine that is connected to the supply it is imperative that the safe ***isolation procedures*** are carried out. (Course EXP-MN-SE180 for "Electrical Safety"

See also operator course EXP-PR-EQ150 for "generators and motors", paragraph 12.7 on this subject

7.1. FAULT TYPES

There are essentially four types of electrical faults to be found in electrical machines.

1. Short between windings; breakdown in installation between two or more phase groups.

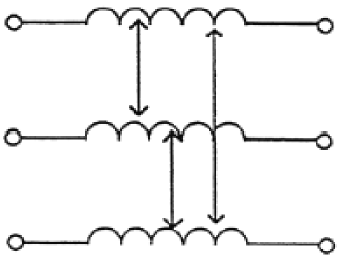
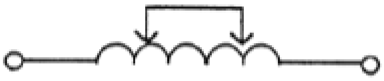


Figure 69: Motor fault – Shorts between windings



2. Shorted turns; the insulation breaks down between the turns of the coil.

Figure 70: Motor fault – Shorts inside a winding

3. Open winding; a break in continuity of the winding wire.

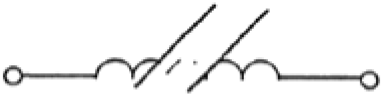
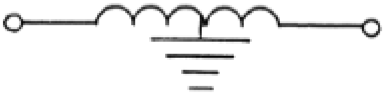


Figure 71: Motor fault – Open winding



4. Ground fault; a breakdown in insulation between the windings and the case or frame of the machine.

Figure 72: Motor fault – Insulation break in winding

When testing a motor the tests should ensure that all four possible fault types are eliminated. The tests carried out fall into two categories:

1. Insulation resistance; in order to test the insulation resistance a high voltage must be placed across the insulated parts, for this test an insulation tester set on MΩ is used.

2. Continuity test; in order to verify that the circuit is continuous; a multimeter set on Ω is used. By taking a precise reading and comparing the result with other windings the problem of shortened turns can also be diagnosed. An insulation tester can be used on its Ω scale.

We will concentrate on the testing of three phase machines but the same principle can be applied to the testing of other machines (e.g. DC, single phase etc). The following chart shows the type of test to be carried out and the correct instrument to be used. You will note that the method for testing six terminal motors is different from internally connected machines (i.e. Star or Delta).

The reason for this is that in six terminal machines the windings are electrically separated where in the three terminal machines the three windings are connected together inside the machine, hence there would be no point in subjecting the windings to a high voltage test.

The only way we would be able to initially detect a short circuit between windings on a three terminal motor would by looking for a change of resistance in the continuity through the windings.

Test equipment for Low Voltage Motors

Fault	**Six terminal Motor**	**Star connected**	**Delta connected**
Short between windings	Insulation and continuity tester Test voltage 500v @ 1mA	Digital Multimeter set to Ω	Digital Multimeter set to Ω
Shorted turns	DMM set to Ω	DMM set to Ω	DMM set to Ω
Open circuit winding	DMM set to Ω	DMM set to Ω	DMM set to Ω
Fault to Earth	Insulation and continuity tester Test voltage 500V @ 1mA	Insulation and continuity tester Test voltage 500V @ 1mA	Insulation and continuity tester Test voltage 500V @ 1mA

Table 12 :LV Motors types of electrical faults and testing methods

For HV Motors (6 and 11 kV) use a 5000 V megohmmeter (instead of 500 V). And for continuity test, use an ohmmeter, the same one.

7.2. TESTING – INSULATION RESISTANCE

The wide range of types and sizes available of electrical machines means that it is difficult to suggest definite hard and fast rules regarding what a normal reading should be. The following however should be used as guidance.

The insulation resistance of a machine, both between windings and between windings and earth or (frame) should be no less than that given by the following formula:

Minimum insulation resistance in MΩ = Supply voltage / (1000 + HP) = $\frac{Supply - voltage}{1000 + HP}$

It can be seen from the formula that on voltage up to 500V, for smaller machines the insulation resistance should be a minimum of about 0.5 MΩ. It also follows that on higher voltages a higher minimum insulation resistance is required, where on very large machines the minimum acceptable value would be reduced.

Example: a 3.3 kV, 500 HP motor is to be insulation tested, what is the minimum resistance acceptable for this test?

Resistance in MΩ = $\frac{Supply - voltage}{1000 + HP}$ = 3300 / (1000 + 500) = 3300 / 1500 = **2,2 MΩ**

7.3. CONTINUITY

There are a number of points here:

While a simple indication that there is electrical continuity through a winding eliminates the possibility of an open circuit fault, it is important to obtain an actual, accurate reading in ohms in order to rule out the possibility of shorted turns.

On three terminal motors, this test would also be used to access the status of insulation between windings.

The readings obtained will vary greatly from machine to machine, anything from less than one ohm to over 1kΩ, generally the larger the motor the continuity resistance of the windings.

Having obtained a precise measurement of winding resistance it is then possible to compare this reading with the readings taken across the other windings.

This comparison of windings is one of the most useful indications as to a motors condition, the readings should all be equal to within a very small margin, this aspect of “balanced windings” applies only to three phase machines, DC and single phase motors are more problematic in this respect.

8. A.C. MOTOR BREAKING SYSTEMS

There are a number of braking systems available both mechanical and electrical, we are going to look at two of the electrical systems commonly found in industry:

- AC Plugging
- DC Injection

I have not seen so many braking systems in our (oil & gas) industry. Only on hoists and overhead cranes, but there also, they were more frequently equipped with mechanical braking systems. However, I remember having worked in troubleshooting and maintenance, on electrical braking system (but I do not remember where…), so…, let's see it

8.1. AC PLUGGING

Plug braking commonly known as "plugging" is one of a number of systems employed to bring about rapid deceleration of an electric motor.

The system is entirely electrical with no mechanical or frictional devices, which is useful where space is limited. All the components can be located away from the motor or machine. When braking is required the power supply to the motor is reversed until the moment the drive stops, therefore plugging is a timed reversal of the supply.

- There are two main ***factors*** that must be taken ***into account*** when designing a plugging system these are:

    1. The risk of ***short circuit*** when reversing the power supply

    2. The motor ***restarting in*** the ***reverse*** direction if the power is not disconnected at the moment of stopping.

- In practice these factors can be taken into account by using the following power and control circuits.

    1. The running and braking ***contactors*** are ***mechanically interlocked*** so that only one circuit can be operated at any one time, reducing the risk of short circuit. In automatic systems mechanical and electrical interlocks should be employed.

    2. To prevent restarting in the reverse direction it is usual to employ a ***safety relay*** together with a ***speed sensing switch*** mounted on the motor shaft and connected as shown.

8.1.1. Plugging Power circuit

It is exactly the same circuit than for a 2 directions motor.

Thermal protection is installed on “normal running” branch. If installed upstream the derivation connection (for running and plugging diversion), it can be actuated when braking to high current drawn at that time.

Protection is here represented as the (old) typical one : fuses + thermal relay

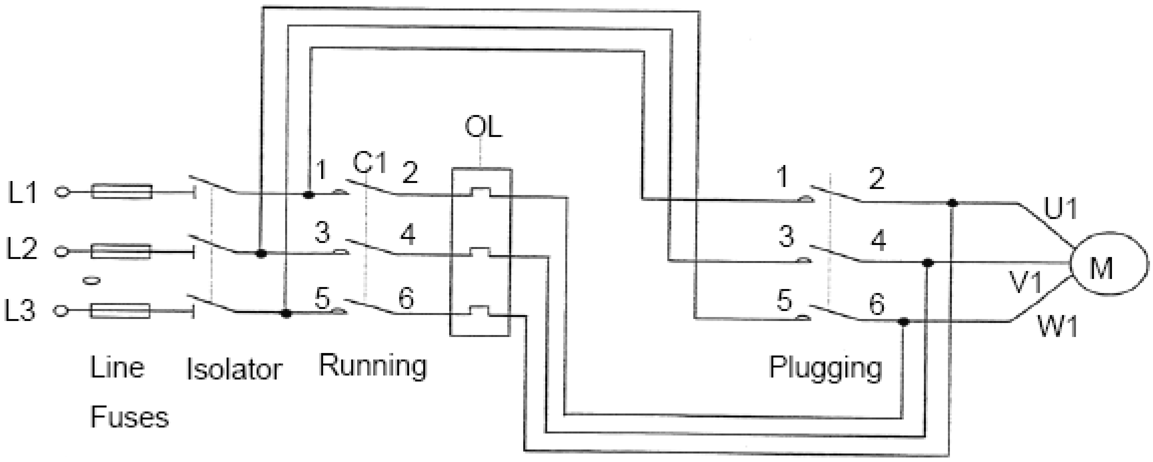


Figure 73: Motor Plugging system – Power circuit diagram

8.1.2. Plugging control circuit

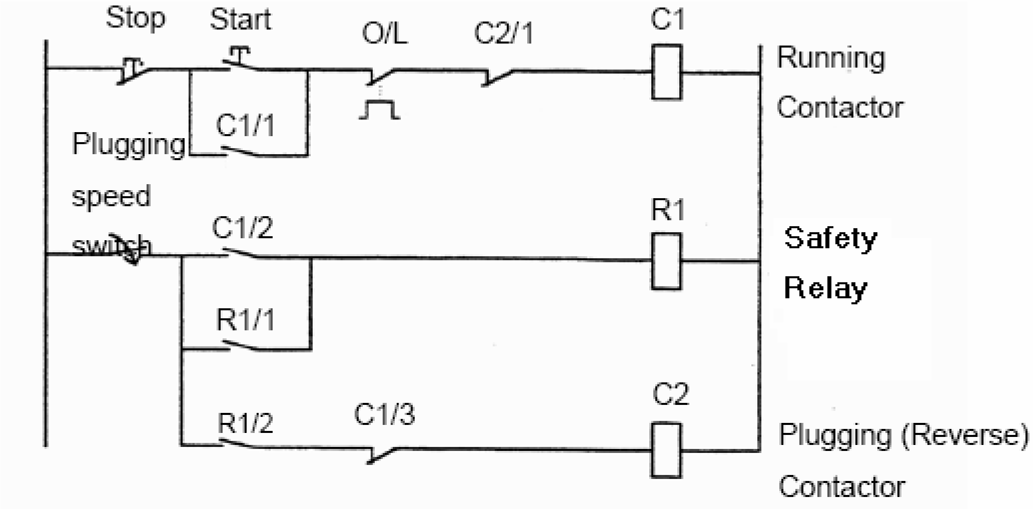


Figure 74: Motor Plugging system – Control circuit diagram with speed switch

Operation:

Pressing the start button closes the running contractor C1 which is retained by contacts C1 / 1, the three phase supply is now switched to the motor via the overload unit, and the motor is now running.

Contacts C1 / 2 are now closed preparing the circuit to relay R1, as the motor gathers speed the contacts of the plugging speed switch closes to complete the circuit to relay R1 which now closes together with contacts R1 / 1 which retain relay R1.

Contacts R1 / 2 prepare the circuit to contactor C2 although at this stage C2 cannot close due to electrical interlock contactor which is at present held open.

Pressing the stop button de – energises running contactor C1 which disconnects the supply to the motor. Auxiliary contact C1 / 3 (back to its NC position) energises contactor C2, which restores the power to the motor windings but in the reverse direction.

Reversing the power to the motor causes a rapid reduction in forward speed, at the point when the motor reaches standstill the plugging switch contacts open to de – energise relay R1 which in turn opens the plugging contactor C2.
The running and braking cycle is now complete.

Any extra movement of the shaft may cause the plugging switch contacts to remake momentarily but as the contacts of safety relay R1 are now open the plugging contactor cannot be re – energized.

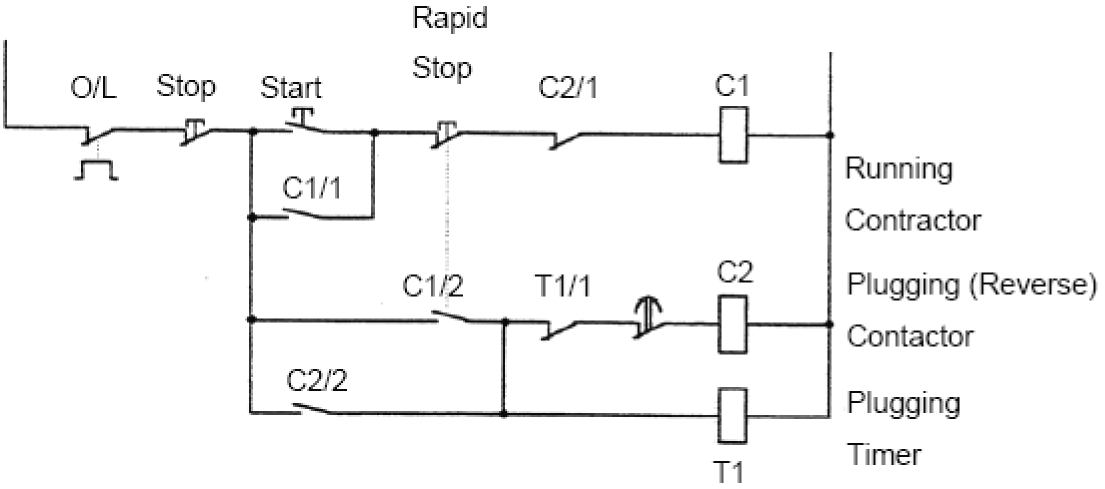


Figure 75: Motor Plugging system – Control circuit diagram with time delay relay

Variation:

The plugging speed switch is ideal in situations where the load on braking varies. As the stopping time will vary each time, the switch detects when the motor is at rest. If the system were breaking approximately the same load each time, then the braking time will not vary. Therefore a timed circuit would be appropriate.

It is a case of selecting the most suitable system for the drive: the timed braking.

A plugging will be a timed reversal of the supply. An alternative control circuit can be used or when / where a plugging speed switch is not available, being achieved by the use of a timer relay.

8.1.3. Protections and design

8.1.3.1. Contactors

The power drawn from the supply during braking is greater than the power during normal starting; therefore the contactors used are generally rated against braking current as opposed to starting current.

Contactors are normally designed to handle 8 x FLC on closure and 1 x FLC on opening, the plugging contactor opens when the motor reaches zero speed, at which point currents up to 8 x full load will be present.

For this reason the system must be designed with plugging contactors capable of carrying higher current, i.e. dissipating more heat, capable of breaking higher currents and dispersing greater arc energy.

8.1.3.2. Overload / Thermal unit

If the plugging circuit is to be used for frequent operation, then consideration needs to be taken regarding the braking current.

In the plugging power circuit it can be seen that the breaking current does not flow through the overload / thermal unit, this current is high and could cause nuisance tripping if it did so.

The breaking current is only present for seconds, therefore the circuit is not put at risk of damage because the absence of tripping unit. Anyway, there is still an upstream protection, the fuses and/or the breaker.

8.1.3.3. Motors

The motors is subject to higher mechanical stress when plug breaking, the designer must therefore take this into account when planning shaft sizes, keyways, belt, chain or geared units in the drive system.

The extra power in the system used by the motor will appear as heat in the windings. If starting and stopping is frequent the temperature in the motor may rise to dangerous levels resulting in possible winding damage.

Manufacturer's recommendations should be followed when selecting motors for this type of duty.

8.2. D.C. INJECTION BREAKING

8.2.1. D.C. Injection braking principle

Direct current injection braking is achieved by disconnecting the AC supply from the motor and applying a DC supply to any two terminals of the stator winding. The advantages of this system are:

1. No mechanical coupling is fitted to the motor.
2. The motor cannot run in reverse as with plugging if the plugging switch is badly adjusted.
3. The rotor is free to be rotated manually after the braking period.
4. The time to brake the motor to a standstill can be varied by a simple direct current.

DC injection braking allows machines to be controlled smoothly and effectively by reducing the natural run down time of the machine. The units have wide range of applications from the braking of heavy loads with long run down times to equipment such as circular saws, bench grinders, pedestal drilling machines, etc where stopping the motor quicker, such as with an emergency switching device, would increase the risk of potential safety hazards.

This device (DC injection braking) is primarily designed for the replacement of mechanical methods of braking or reverse current braking.

8.2.2. Operating principle of D.C. injection

A D.C. voltage is applied to the stator windings of the motor after it has been disconnected from the supply; this produces a stationary magnetic field.

The stationary field retards the rotors movement resulting in a smooth braking action. The amount of braking torque is dependant on the level of injected current, which can be varied over a wide range.

The period of injection is also adjustable to enable the current to be fine turned against braking time, which allows for different rates of braking for different applications.

8.2.3. Operation of D.C. injection braking

Let(s consider an existing DC supply “box” or “unit” (itself supplied in A.C.) with the hereafter explained equipment

When the stop button for the machine is operated, the motor contactor de-energises closing the normally closed auxiliary contacts C1 / 2.

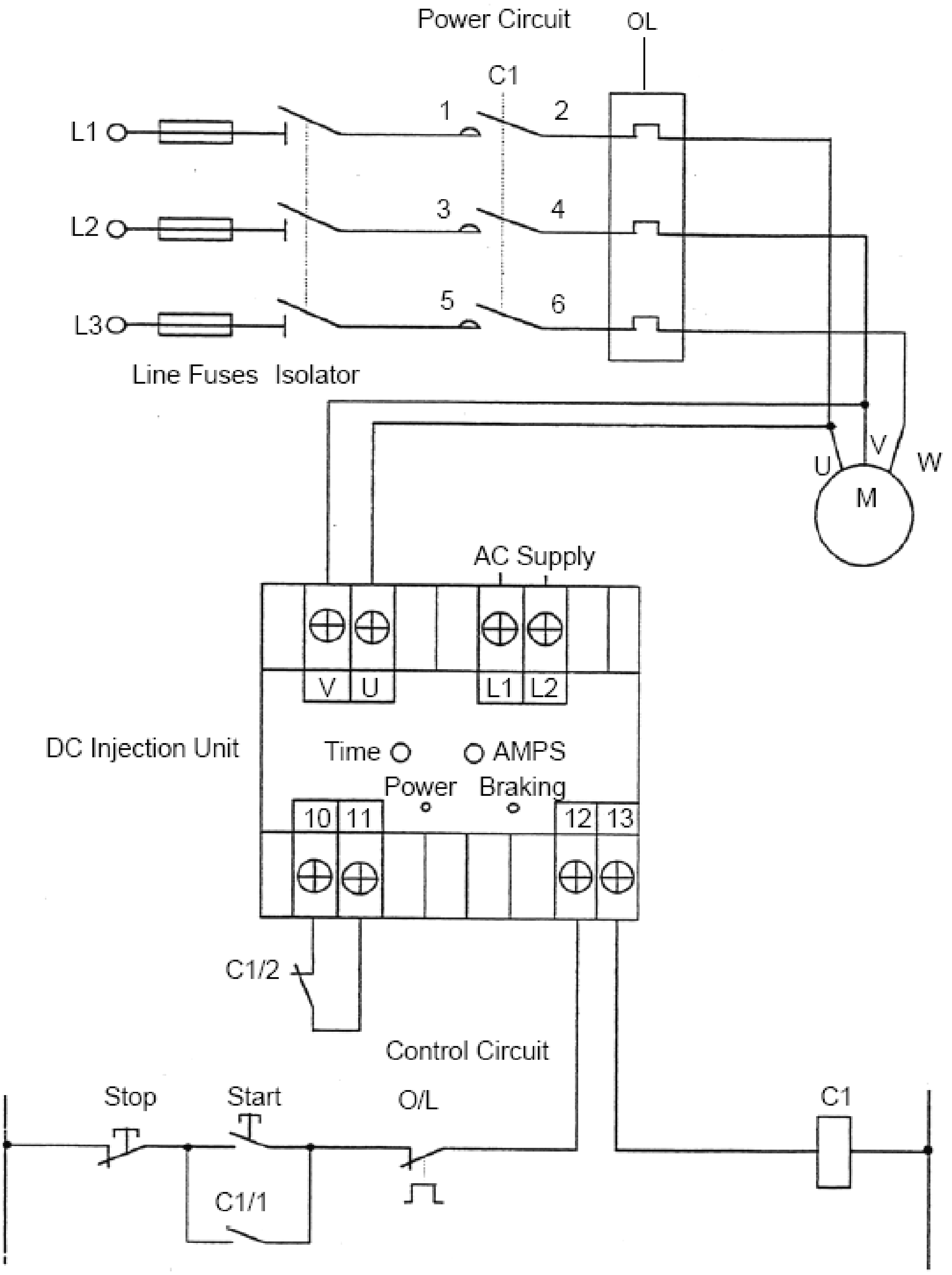


Figure 76: Scheme of a D.C. injection system for A.C. motor braking

This activates the unit by connecting together terminals 10 & 11 which signal the unit, that the motor contactor has been released, the control supply is then locked open circuit through terminals 12 & 13.

The DC braking current is supplied to the motor after a period of about 0.4 seconds, this delay allows any remaining induction voltage in the motor to reduce to a value which will not damage the power semi – conductors

It must be ensured that the motor is disconnected from the three-phase supply before DC is injected.

After the braking circuit is closed the DC is injected.

After the expiry of the braking time, the braking current is switched off and the locking relay (which is locking the control supply open circuit) releases after approximately 0.4 seconds which allows the motor to be re – started.

9. DIRECT CURRENT MOTORS

For theory, refer to operators courses EXP-PR-UT010 “Electricity” and course EXP-PT-EQ150 “generators and motors”.

We do have limited number of DC motors on Oil & Gas sites; we consider here the specific troubleshooting on DC motors

Faults on DC motors can be categorised basically in two categories:

- Mechanical faults
- Electrical faults

9.1. ELECTRICAL FAULTS

In general, electrical faults result from

- an open circuit,
- short circuit,
- ground fault,
- incorrect connection
- or improper voltage.

For proper operation, keep a motor clean and dry. Conduct insulation tests regularly.

If a DC motor does not perform as it should:

1. Check that the supply voltage is correct and ensure that the armature and field coils are properly connected

2. Locate open circuits using continuity tests of the field and armature circuits

3. Determine whether there are ground faults and insulation break-down by using a megohmmeter

Armature Faults:

Short circuits are most likely to occur in the armature itself. To perform tests on the armature, it is necessary to remove it from the machine. Once removed, perform the following tests:

Grounded coil:

Connect a 120V supply and a test lamp between any commutator bar and the shaft. If the test lamp lights, the armature is grounded. Or using a multi meter and doing a resistance test

Open coil:

For lap wound armatures, apply a low value of voltage to two bars on opposite sides of the commutator. As the leads of the voltmeter are moved around the commutator measuring the voltage between adjacent bars, you should observe equal voltages. In the event of an open coil or bar, the full applied voltage will be observed between the bars connected to the faulty coil

Shorted coil:

Use a growler (see Figure) to test for shorted coils. A growler is a device that produces a strong alternating magnetic field.

When placed in a growler, the armature conductors are cut by the magnetic field. If a coil is shorted, high current flows in the coil.

A steel strip will vibrate excessively when passed over a slot containing a shorted coil slot.

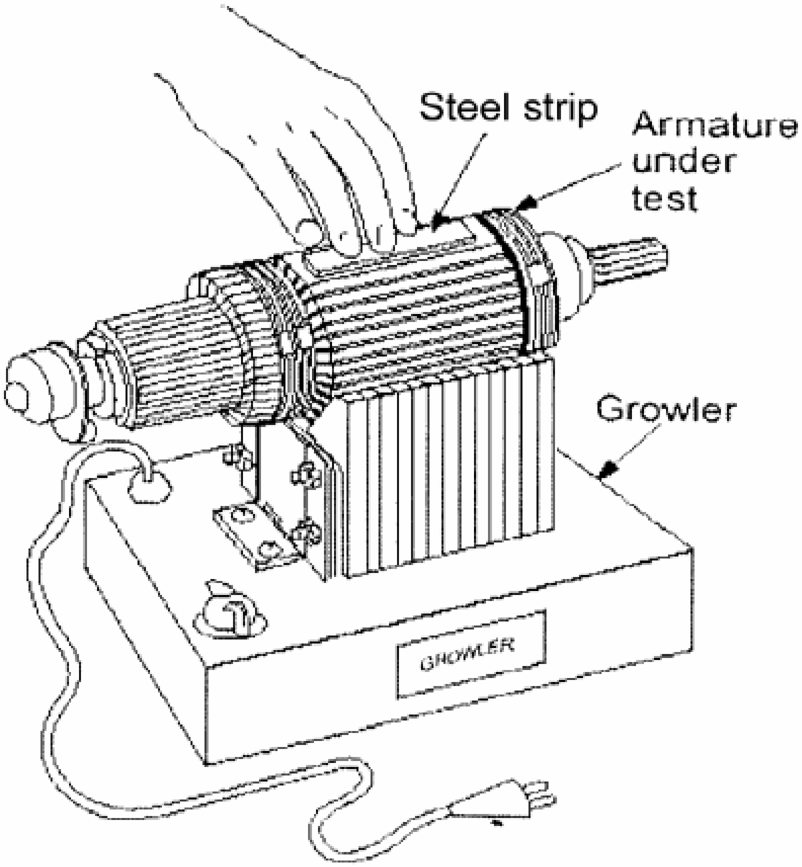
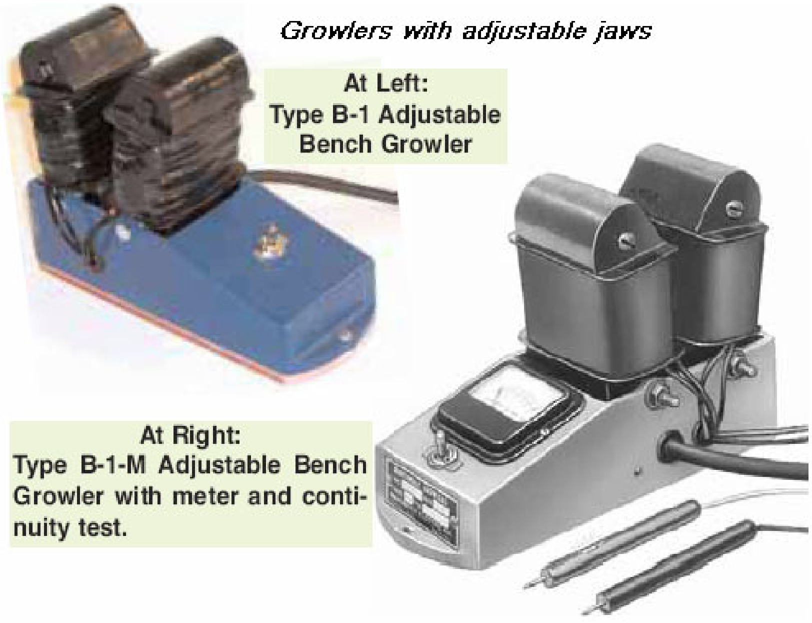


Figure 77: Using a "Growler" to test for shorted coil


Growlers with adjustable jaws
At Left:
Type B-1 Adjustable Bench Growler
At Right:
Type B-1-M Adjustable Bench Growler with meter and continuity test.

What is a growler?

When an alternating current is passed through a Growler, it sets up a magnetic flux in the iron of the armature or stator spanned by the jaws of the Growler.

Figure 78: Example of Growler units – Bench type - Martindale

As this flux passes through any coil, it induces a potential. A current will flow if the coil is short-circuited.

When current flows, it sets up a magnetic field around the shorted coil which can be detected with an iron feeler. (The increased load on the Growler sometimes changes the tone of the hum; hence the name "Growler".)

In many cases a meter can be used to measure a change in magnetic flux or to measure the increased current requirements of the Growler (*depending the type of growler unit*). Open coils can also be found..

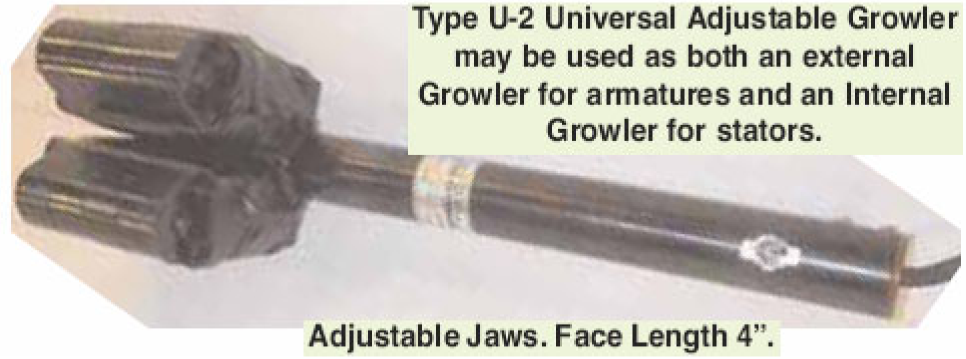

Type U-2 Universal Adjustable Growler may be used as both an external Growler for armatures and an Internal Growler for stators.
Adjustable Jaws. Face Length 4".

Figure 79: Example of Growler units – Portable type - Martindale

Type U-2 Growler has adjustable jaws 4" long, and may be used on armatures over 1", and on stators over 5-3/4" inside diameter. It is connected on a separate meter unit

How Growlers are used?

The most common way of using a Growler is the “feeler method” in the Growler spans a slot containing a coil, and a “feeler” of iron, such hack-saw blade is held about 1/4” above the slot containing the other the same coil.

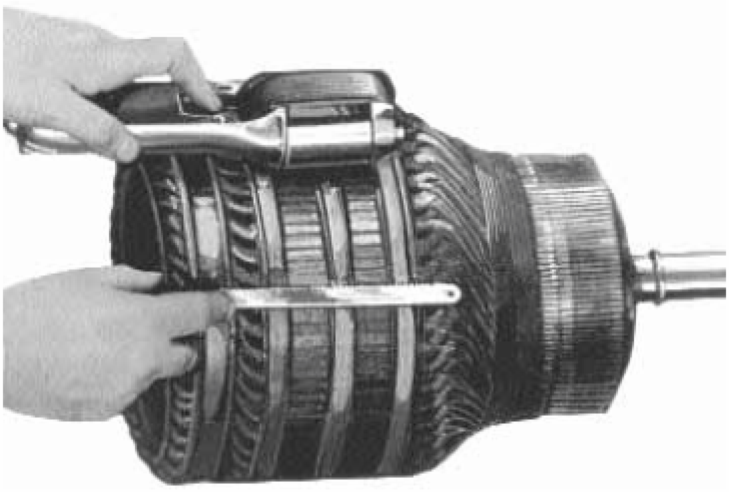


Figure 80: Use of a Growler (Martindale type F) to test a DC rotor

If the coil is shorted the feeler will be pulled down to the slot and will stick and vibrate.

The action is very positive and is recognized instantly.

The feeler can also be used on the same side of the coil that is spanned by the Growler, either a separate feeler or the convenient built-in feeler of
Open circuits can be detected by shorting adjacent commutator bars with a screw driver, or any other piece of metal. Good coils will spark as the bars are shorted. No sparks indicate the coil is open. Test field coils by shorting lead wires. Another way is to use a continuity tester

On “our” sites, we do not have so many DC motors (already said above…). Probably, you are not (and will never be provided with) equipped with Growler in your workshop, and, consequently you will never have the opportunity to use it (I never used it on Total sites). But…, this equipment (the portable one) can be used to test stators, so it can be useful to test status of stator coils when you have some doubt….

Brush Commutator maintenance

When operated correctly, a DC motor should not over-heat or spark at the brushes. Brush sparking may result from any of the conditions listed in Table

Condition	**Action**
Wrong connection of the inter poles	Connect inter poles properly
Poor brush contact	Re-seat the brushes
Worn or incorrect brushes	Replace the brushes
Improper brush tension	Adjust to manufacturer’s specifications
Mica sticking out on the commutator	Undercut the mica
Dirty commutator	Remove the surface contaminants
Electrical faults in the armature	Remove and test

Table 13: DC motor - Brush commutator maintenance

9.2. MECHANICAL FAULTS

Mechanical faults can result in over-heating or excessive vibration. Common mechanical faults include:

- worn bearings
- armature imbalance
- improper alignment of the motor and the mechanical load
- loose coupling between the motor and the load
- loose mounting bolts and unbalanced mechanical load

Regular maintenance includes cleaning, lubricating and routine inspection of the mechanical condition of the motor and load, DC motors as per the AC motors.

10. MAINTENANCE OF A TYPICAL ELECTRIC MOTOR

The maintenance team often has to replace, repair and test all types of electric motors.

A French manufacturer's installation and maintenance instructions are given below. These instructions more or less summarise all the operations and operating guidelines for installing and maintaining an electric motor

10.1. RECEPTION

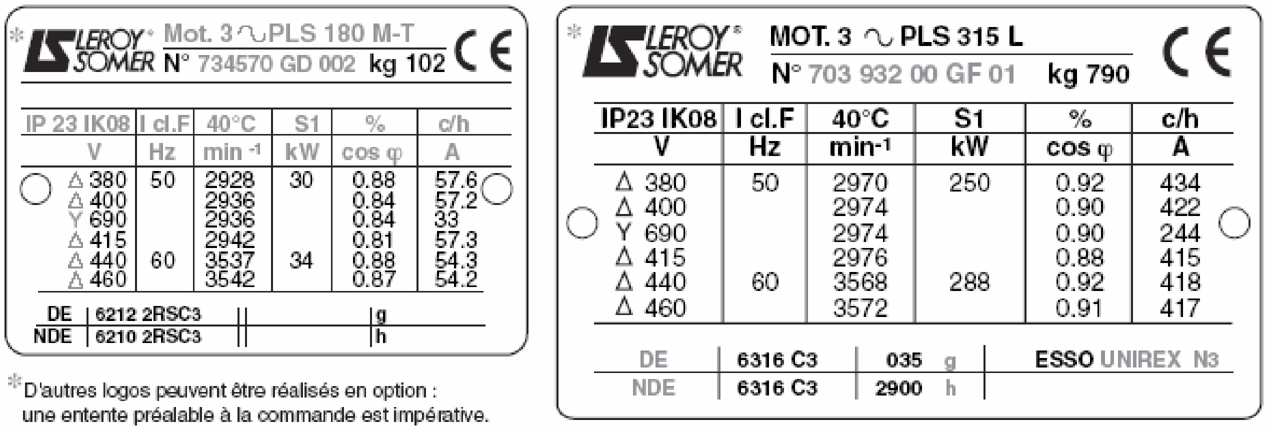
When you receive your motor, check that it has not been damaged during transport.

If there are obvious signs of damage, contact the carrier (you may be able to claim on their insurance) and, after a visual check, turn the motor by hand to detect any malfunctions.

10.1.1. Identification

Already covered in the course, but consider this as revision.

As soon as you receive the motor, check that the nameplate on the machine conforms to your order.



LEROY SOMER Mot. 3∿PLS 180 M-T
N° 734570 GD 002 kg 102

IP 23 IK08	I cl.F	40°C	S1	%	c/h
V	Hz	min⁻¹	kW	cos φ	A
Δ 380	50	2928	30	0.88	57.6
Δ 400		2936		0.84	57.2
Y 690		2936		0.84	33
Δ 415		2942		0.81	57.3
Δ 440	60	3537	34	0.88	54.3
Δ 460		3542		0.87	54.2

DE	6212 2RSC3		g
NDE	6210 2RSC3		h

*D'autres logos peuvent être réalisés en option :
une entente préalable à la commande est impérative.

*LEROY SOMER® MOT. 3 ∿ PLS 315 L
N° 703 932 00 GF 01 kg 790

IP23 IK08	I cl.F	40°C	S1	%	c/h
V	Hz	min⁻¹	kW	cos φ	A
Δ 380	50	2970	250	0.92	434
Δ 400		2974		0.90	422
Y 690		2974		0.90	244
Δ 415		2976		0.88	415
Δ 440	60	3568	288	0.92	418
Δ 460		3572		0.91	417

DE	6316 C3	035 g	ESSO UNIREX N3
NDE	6316 C3	2900 h	

Figure 81: Typical manufacturer's nameplate

Definition of the nameplate symbols:

<table>
<tr><td colspan="3">CE Legal mark indicating that the equipment is compliant with the requirements of the European Directives.</td></tr>
<tr>
<td>MOT 3 ~: Three-phase ac motor
PLS: Series

180: Shaft height
M: Housing symbol
T: Impregnation index
<i>Motor no.</i>
734570: Motor batch number
G: Year of production
D: Month of production
002: Serial number
70393200: Motor batch number
G: Year of production
F: Month of production
01: Serial number</td>
<td>kg: Weight
IP23: Protection index
IK08: Shock resistance index
I cl. F: Insulation class F
40°C: Contractual ambient operating temperature as per IEC 60034-1
S: Duty
%: Operating factor
c/h: Number of cycles per hour
V: Supply voltage
Hz: Supply frequency
min^{-1}: Rpm
kW: Rated power
cos φ: Power factor
A: Rated current
Δ: Delta connection
Y: Star connection</td>
<td><i>Windings</i>
DE: Drive End
Drive end bearing
NDE: Non Drive End
Non drive end bearing
g: Amount of grease used for each regreasing operation (in g)
h: Greasing interval (in hours)
UNIREX N3: Grease type</td>
</tr>
</table>

Table 14: Definition of symbols used on nameplates

10.1.2. Storage

Prior to commissioning, the motors must be stored:

- in a dry place: if the relative humidity level exceeds 90% the machine's insulation can fall very rapidly to almost zero at around 100% humidity; monitor the condition of the rustproofing of unpainted parts.

  For very long-term storage periods the motor can be placed in a sealed bag (e.g. heat-sealable plastic) containing desiccant bags:

- away from frequent high temperature variations to prevent condensation forming during the storage period.

- if the area is subject to vibrations, try to reduce the effect of these vibrations by placing the motor on a support which will damp them out (rubber mat or similar) and turn the rotor a fraction of a turn every two weeks to prevent the bearing rings from becoming marked.

- do not remove the rotor locking device (where roller bearings are fitted).

Even if the motor has been stored in the correct conditions, certain checks must be carried out before it is started:

Lubrication

Non regreasable bearings

Maximum storage: 3 years. After this time the bearings must be replaced.

Regreasable bearings

Greases used by LEROY-SOMER

	Grade 2 grease	Grade 3 grease	
Storage period	Less than 6 months	Less than 1 year	The motor can be put into service without regreasing
	More than 6 months Less than 1 year	More than 1 year Less than 2 years	Regrease before entry into service
	More than 1 year Less than 5 years	More than 2 years Less than 5 years	Remove the bearing Clean it Completely renew the grease
	Over 5 years	Over 5 years	Change the bearing Regrease completely

Table 15: Use of greases and bearings according to the storage period

The motor manufacturer's nameplate indicates the grease type and weight (in g) to be used for each regreasing operation, and the greasing frequency (in hours).

Electric motors are industrial products.

Therefore they must be installed by qualified and competent personnel.

The safety of persons, animals and property must be guaranteed when incorporating or integrating motors into machines: see the standards in force.

10.2. INSTALLATION RECOMMENDATIONS

10.2.1. Checking the insulation

Before starting the motor, you are recommended to check the insulation between the phases and earth, and between the phases.

This check is essential if the motor has been stored for more than 6 months or if it has been in a damp atmosphere.

This measurement is carried out using a megger at 500 volts dc (do not use a magneto system).

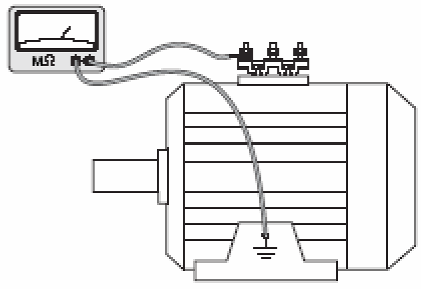


Figure 82: Insulation measurement before entry into service

It is preferable to carry out an initial test at 30 or 50 volts, and if the insulation is greater than 1 megohm, carry out a second test at 500 volts for 60 seconds. The insulation value must be at least 10 megohms when cold.

If this value cannot be reached or if the motor has been splashed with water or salt spray, or kept for a long period in a location with high humidity or if it is covered with condensation, it is recommended that the stator should be dehydrated for 24 hours in an oven at a temperature of between 110° and 120°C.

If it is not possible to dry the motor in an oven:

- switch on the motor, with the rotor locked, at a low three-phase ac voltage reduced to approximately 10% or the rated voltage for 12 hours (use an induction regulator or a step-down transformer with adjustable tappings).
- or supply the 3 phases in series with dc current and with the voltage at 1 to 2% of the rated voltage (use a dc generator with separate excitation or batteries for motors less than 22 kW).
- NB: the ac current must be checked using a clamp-on ammeter, the dc current must be checked using a shunt ammeter. This current must not exceed 60% of the rated current.

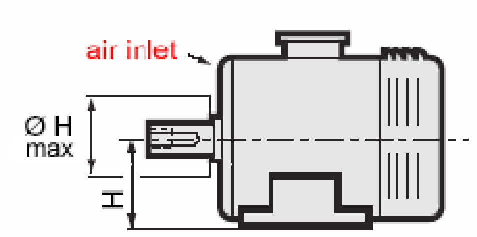
It is recommended that a thermometer should be placed on the motor frame: if the temperature exceeds 70°C, reduce the indicated voltages or currents by 5% of the original value for every 10 degree difference.

During drying, all the motor orifices must be open (terminal box).

WARNING: The dielectric test was performed in the factory, if it has to be repeated, it must be carried out at half the standard voltage rating, i.e.: 1/2 (2U+1000V).

Prior to commissioning for all motors: Run the motor without load, (without mechanical load) for 2 to 5 minutes and check that there are no abnormal noises.

10.2.2. Location - ventilation



LS motors (like those of other manufacturers) are cooled using method IC- 01 (IEC 34-6 standard), i.e. self-ventilated cooling air taken from surrounding ambient air.

Figure 83: Motor cooling / ventilation

The cooling is by a fan at the non drive end (NDE) of the motor; the air is drawn in through the drive end (DE) and blown through the housing to guarantee the thermal equilibrium of the motor whatever the direction of rotation.

The motor must be installed in an adequately ventilated location, with sufficient clearance for the air intake and outlet.

If the ventilation circuit becomes blocked (even accidentally) this will affect the motor's operation.

It is also necessary the check that the hot air is not being recycled; if this is the case, a fresh air supply duct and a hot air evacuation duct must be provided to prevent the motor overheating.

In this case and if the air circulation is not provided by an auxiliary ventilation system, the duct dimensions should be sufficient to guarantee that the pressure drops are negligible compared to those of the motor.

Installation

The motor must be installed in the position specified in the order, on a base which is sufficiently rigid to prevent distortion and vibration.

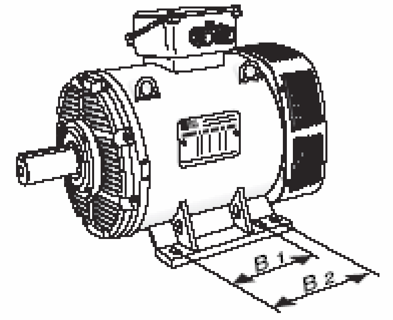


Figure 84: Installation of an electric motor

When the motor feet have six attachment holes, it is preferable to use those corresponding to the standard dimensions for the motor power rating (see the asynchronous motor technical catalogue) or, where this is not possible, those corresponding to B2 (see figure).

Ensure there is easy access to the terminal box and, where applicable, to the grease nipples.

Use lifting equipment compatible with the weight of the motor (indicated on the nameplate).

When the motor is equipped with lifting rings, they are designed to lift the motor only and must not be used to lift the complete machine when the motor is coupled to it.

Note 1: When installing a suspended motor, it is essential to provide a protection system in case the attachment breaks.

Note 2: Never stand on the motor.

10.2.3. Coupling

10.2.3.1. Preparation

Turn the motor by hand before coupling, to detect any damage due to the handling operations.

Remove the shaft protection, where fitted.

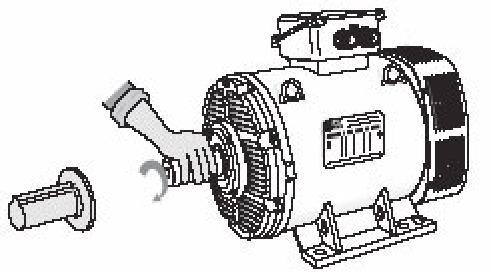
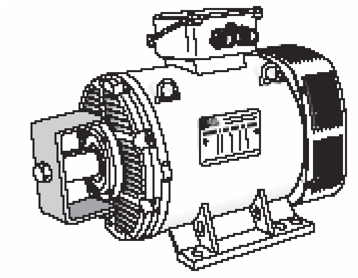


Figure 85: Turn the motor by hand

10.2.3.2. Rotor lock

For custom-made motors with roller bearings, remove the rotor lock.



In exceptional cases when the motor has to be moved after the coupling device is fitted, the rotor must again be immobilised.

Figure 86: Rotor lock

10.2.3.3. Balancing

Rotating machines are balanced in compliance with the ISO 8821 standard:

- half key when output shaft face is marked H: standard,
- keyless when the output shaft face is marked N,
- full key when the output shaft is marked F.

Thus all coupling components (pulley, sleeve, ring, etc.) must be balanced accordingly.

The key must be adapted if the coupling component does not totally cover the length of the key.

Motor with 2 output shafts:

If the second output shaft is not used, and to respect the balancing class, the key or 1/2 key must be solidly fixed in the keyway so that it is not thrown off during rotation (H or F balancing) and it must be protected against direct contacts.

10.2.3.4. Precautions

All necessary measures must be taken to protect yourself against the risks run when there are rotating parts (sleeve, pulley, belt, etc.).

If a motor is to be started when no coupling device is fitted, carefully secure the key in its keyway.

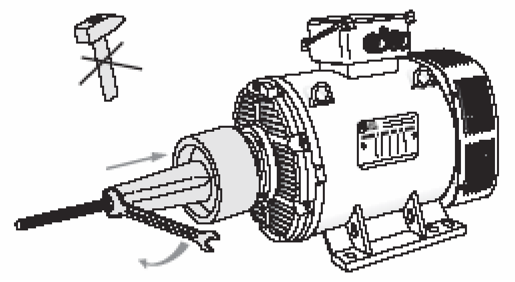
WARNING: the motor may rotate when switched off. This rotation must be stopped:

- pumps: install a nonreturn valve.
- mechanical components: install an antirotation system or a holding brake.
- etc.

10.2.3.5. Tolerances and adjustments

The standard tolerances are applicable to the mechanical specification values published in the catalogues. They are compliant with the requirements of the IEC 72-1 standard.

- There must be strict compliance with the transmission component manufacturer's instructions.
- Avoid impacts which may deteriorate or damage the bearings.



Use a screw device and the threaded hole in the output shaft, and a special lubricant (e.g. molykote grease) to facilitate the installation of the coupling.

Figure 87: Installing the coupling

The hub of the transmission device must be:

- fully in contact with the shoulder of the shaft or, where this shoulder is not present, against the metal stop ring which forms a labyrinth seal and locks the bearing in place (do not crush the seal).
- longer than the output shaft (by 2 to 3 mm) so that it can be tightened by a screw and washer; if this is not the case a spacer ring must be inserted without cutting the key (if this ring is large it must be balanced).

If there is a second output shaft it must only be used for direct coupling and the same recommendations must be applied.

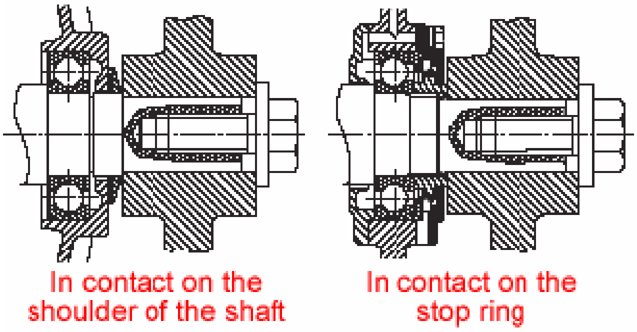

In contact on the shoulder of the shaft
In contact on the stop ring

Figure 88: Coupling fully in contact on the shoulder of the shaft

Important: the 2nd output shaft may be smaller than the main output shaft. The torque it can transmit must not exceed half the rated torque.

Inertia flywheels must not be fitted directly on the shaft but installed between the bearings and coupled by a sleeve.

10.2.3.6. Direct coupling to the machine

If the mobile component (pump or fan turbine) is mounted directly on the motor output shaft, check that this device is perfectly balanced and that the radial force and the axial thrust are within the limits indicated in the catalogue for the strength of the bearings.

10.2.3.7. Direct coupling by coupling sleeve

The coupling sleeve must be chosen taking into account the rated torque to be transmitted and the safety factor dependent on the electric motor starting conditions.

The machines must be carefully aligned so that any lack of concentricity and/or parallelism of the two half-sleeves is compatible with the coupling sleeve manufacturer's recommendations.

The two half-sleeves must be provisionally assembled to make it easier to alter their relative positions.

Adjust the parallelism of the two shafts using a gauge.

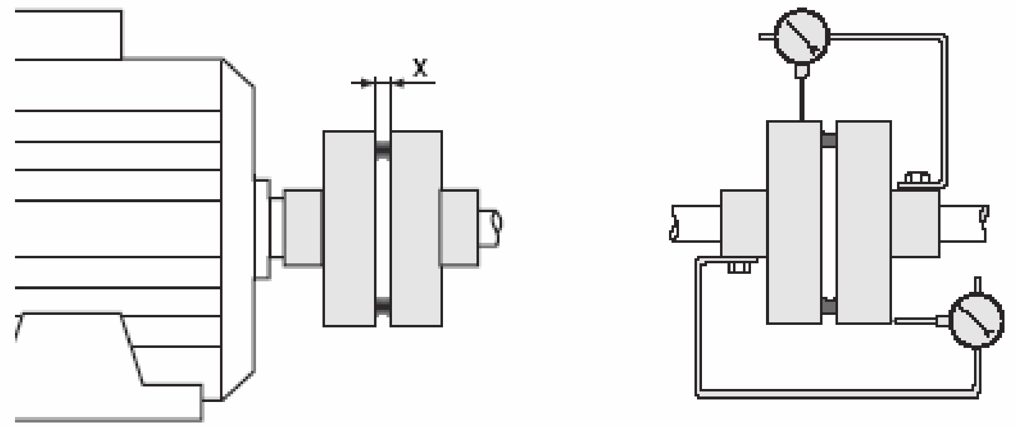


Figure 89: Adjusting the parallelism

Measure the distance between the two coupling surfaces at a point on the circumference; rotate through 90°, 180°, and 270° with respect to this initial position and measure each time.

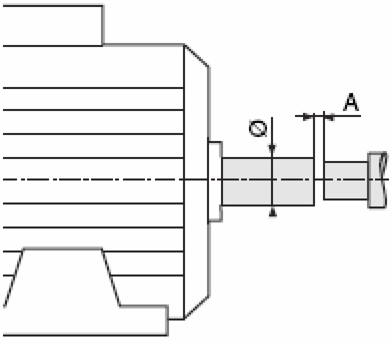
The difference between the two extreme values of value "x" must not exceed 0.05 mm for standard couplings.

10.2.3.8. Direct coupling by rigid coupling sleeve

The two shafts must be aligned to meet the coupling sleeve manufacturer's tolerances.

Respect the minimum distance between the shafts to allow for the expansion of the motor shaft.

Beyond this, prior consultation is necessary.



Ø (mm)	A (mm)
9 à 55	1
60	1.5
65	1.5
75	2
80	2

Figure 90: Tolerances with rigid sleeve coupling

10.2.3.9. Transmission by belt pulleys

The diameter of the pulleys can be chosen by the user.

Cast iron pulleys are not recommended from diameter 315 mm for rotation speeds of 3000 rpm and above.

Flat belts cannot be used for rotation speeds of 3000 rpm and above.

Fitting the belts

To allow the belts to be fitted correctly, provide the possibility of an adjustment of plus or minus 3% with respect to the calculated distance between centres (E).

Never use force when fitting the belts.

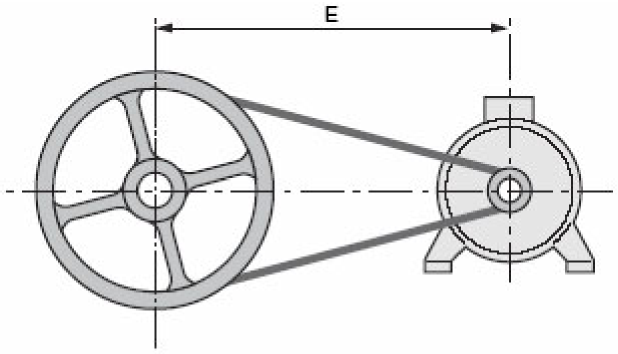


Figure 91: Fitting the belts

For toothed belts, position the teeth in the pulley grooves.

Alignment of the pulleys

Check that the motor shaft is parallel to that of the of receiving pulley.

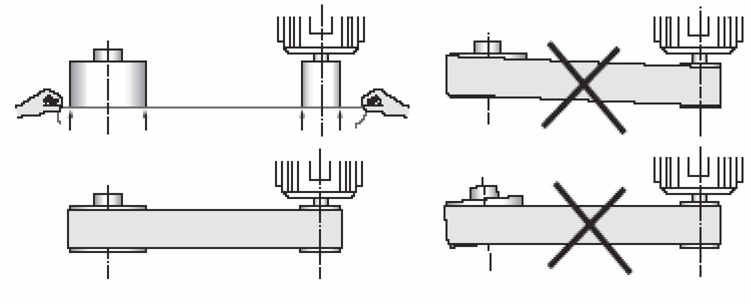


Figure 92: Alignment of the pulleys

Adjusting belt tension

Belt tension must be adjusted very carefully according to the belt supplier's recommendations.

Reminder:

- tension too high = unnecessary force on the bearings which can lead to early wear of the shaft and ball bearings and eventually break the shaft.
- tension too low = vibration (wear of the shaft and ball bearings).

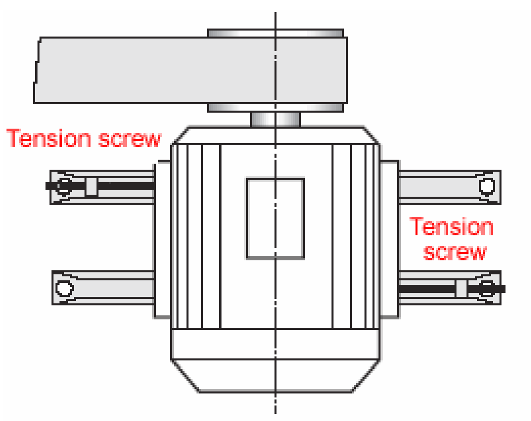
Fixed distance between centres: a belt tensioner presses on the slack part of the belts:

- smooth tensioner roller: presses on the outer face of the belt;
- grooved roller: presses on the inner face of V-belts.

Adjustable distance between centres: The motor is generally mounted on slide rails to obtain the optimum pulley alignment and belt tension adjustment.

Place the slide rails on a perfectly horizontal base.

In the longitudinal direction, the position of the slide rails is determined by the length of the belt, and in the transversal direction by the driven machine's pulley.



Correctly install the slide rails with the tension screws in the direction shown in the figure (the slide rail screw on the belt side must be between the motor and the driven machine).

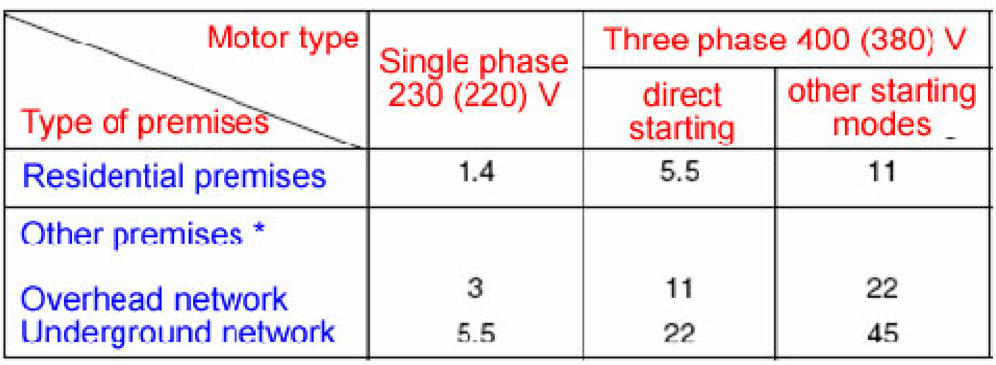
Secure the slide rails onto the base, adjust the belt tension as specified above.

Figure 93: Adjusting the slide rails

10.2.4. Electrical guidelines

10.2.4.1. Maximum power of motors supplied directly from the mains (kW)

The extract from the NFC 15.100 standard indicates the permissible limits for direct starting of a motor connected to the mains electricity supply.



Motor type / Type of premises	Single phase 230 (220) V	Three phase 400 (380) V	
		direct starting	other starting modes
Residential premises	1.4	5.5	11
Other premises *			
Overhead network	3	11	22
Underground network	5.5	22	45

Table 16: Power limit for connection to the mains electricity supply

This configuration is given as an indication only since the motors on our sites are almost always supplied from a separate and/or independent electricity supply.

10.2.4.2. Limiting problems caused by motor starting

To protect the installation, all overheating of the electric cables must be prevented while ensuring that the protection systems are not triggered during starting.

Operating problems created on other equipment connected to the same power supply are due to the voltage drop caused by the current demand which, during starting, can be several times greater than the current absorbed by the motor at full load: 5 to 7 approx. for squirrel cage motors

Even if the electricity supply networks (even private networks) increasingly allow direct starting, the inrush current must be reduced for certain installations.

Smooth operation and progressive starting guarantee the best operating comfort and increase the lifetime of the driven machines.

The two basic parameters for starting squirrel cage asynchronous motors are:

- starting torque,
- starting current.

The starting time is determined by the starting torque, the resistive torque and the total driven inertia.

Depending on the load being driven, it may be necessary to adapt the torque and the current to the machine starting time and to the possibilities of the supply network.

The five basic modes are:

- direct on line (DOL) starting,
- star / delta starting,
- soft starting with autotransformer,
- soft starting with resistors,
- electronic starting.

The "electronic" starting modes control the voltage at the motor terminals during the starting phase and give very progressive smooth starting.

See course EXP-MN-SE120, "LT Distribution Boards" for the different types of starters.

10.2.4.3. Earthing

It is vital that the motor should be earthed to protect the workers.

For the connections, comply with the standards and legislation in force.

A site electric motor always has two earth connections:

- One by a bare cable to the installation's earthing system and then by an external connection on the motor frame
- The second by an earth conductor incorporated in the power supply cable and connected to the terminal designed for this purpose in the terminal box
- The two earth connections are not interconnected at motor level
- Do not mix up or reverse these two connections

See course EXP-MN-SE070, "Earth and neutral"

10.2.4.4. Electric protections

The different types of electric protections, the different electrical supply protection possibilities and the protections integrated in the motor were covered earlier on in this course; see *Protections: thermomagnetic, starting time, locked rotor, heating element, temperature probes integrated in the windings, etc.*

10.2.5. Connecting to the electrical distribution network

10.2.5.1. Terminal box

This box is normally located at the top of the motor near the drive end, has IP 55 protection (minimum for all the motors on the sites) and is equipped with a cable gland.

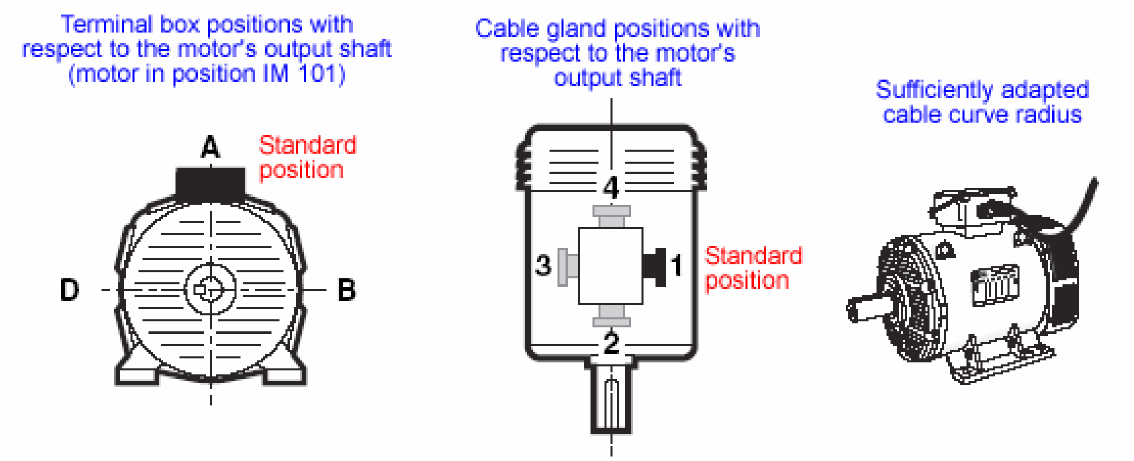

Terminal box positions with respect to the motor's output shaft (motor in position IM 101)
A
Standard position
D
B
Cable gland positions with respect to the motor's output shaft
4
3
1
Standard position
2
Sufficiently adapted cable curve radius

Figure 94: Connection to the terminal box

The cable gland is normally located on the right when viewed from the drive end, but the box's symmetrical construction allows it to be placed in any of the four directions, except where this is not possible due to construction and assembly conditions on certain types of motors. The position of the terminal box can be modified on request (it can be fitted on the right or left when viewed from the drive end).

Cable gland

Ensure that the bend radius of the cables prevents water penetrating into the cable gland.

Adapt the cable gland and its reducer (where fitted) to the diameter of the cable used.

To ensure that the motor terminal box retains its original IP55 protection (or higher), the cable gland sealing must be guaranteed by tightening it correctly (so that it can only be unscrewed using a tool).

If there are several cable glands and if some are not used, ensure that they are always blanked and retighten them so that they can also only be unscrewed using a tool.

For Ex-type motors and in explosion risk zones, only Ex-type cable glands must be used.

10.2.5.2. Cross-sectional area of power supply cables

The higher the current, the greater the voltage drop in the cables (NFC 15.100 standard). The voltage drop should therefore be **calculated for the starting current** to ensure that it is suitable for the application.

Although the most important criterion is the starting torque (or the starting time) the voltage drop should be limited to 3% max. (which corresponds to a drop in torque of the order of 6 to 8%).

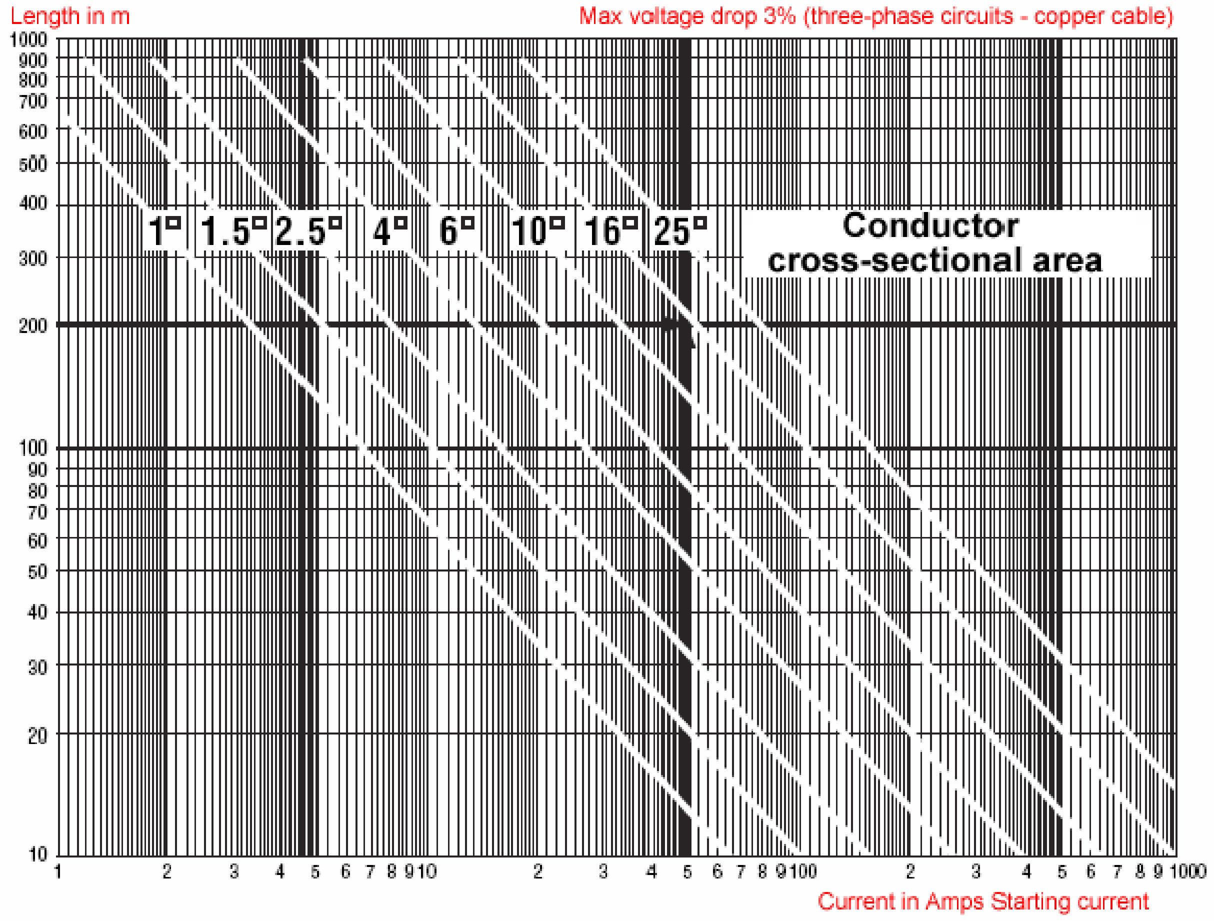


Figure 95: Graph for choosing power supply cable cross-sectional area with a max. voltage drop of 3%

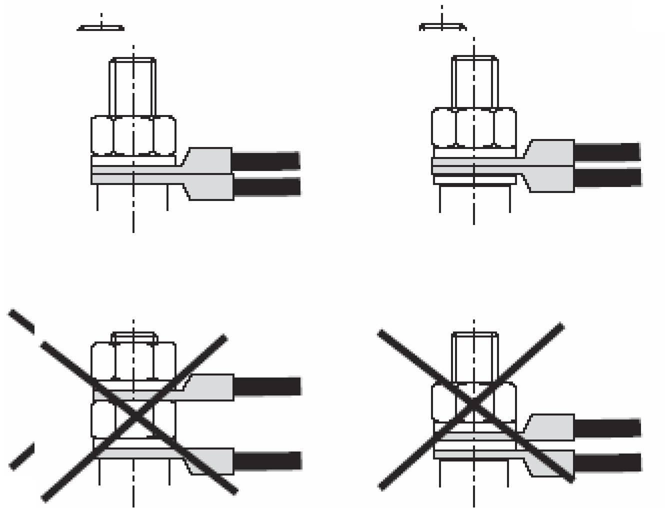
This graph is used to choose the conductors according to length of the supply cable and the starting current to limit the voltage drop to 3% max. with copper conductors.

This table does not relieve the installer of his responsibility to check the protection systems.

Example: for a starting current of 50 A (10 A max. for In) and that a cable length of 200 m, we must choose a cable (copper conductor) with minimum cross-sectional area of 16 mm².

10.2.5.3. Connecting the cables

The ends of the cables must be equipped with terminal lugs adapted to the cross-sectional area of the conductor and to the diameter of the terminals.



They must be crimped-fitted in compliance with the terminal lug supplier's instructions.

The connections must be lug-to-lug if several cables are connected to the same terminal.

Figure 96: Connecting to the terminals

Torque loading (N.m) on the terminal block nuts

Terminal	M4	M5	M6	M8	M10	M12	M14	M16
Steel	2	3.2	5	10	20	35	50	70
Brass	1	2	3	6	12	20	35	50

Table 17: Terminal nut torque loadings

If the cable connections are made without terminal lugs, U-clamps must be used.

For brass terminal strips, if any terminal block nuts are lost they must not be replaced by ordinary steel nuts, only brass nuts must be used.

When closing the terminal box, ensure that the seal is correctly fitted.

As a general rule, check that no nuts, washers or other foreign bodies have fallen into or come into contact with the winding.

10.3. ROUTINE MAINTENANCE

10.3.1. General

Checks after starting

After approximately 50 hours of operation, check the tightness of the motor attachment screws and the coupling component screws. If a chain or belt drive is used, check that the tension is correctly adjusted.

Ventilation

To ensure that the motor operates correctly, remove any dust and foreign bodies which could block the motor housing openings, the drive end shield ventilation louvers and the housing fins.

Precaution: before all cleaning operations, check the sealing (terminal box, etc.).

Dry cleaning (vacuuming or compressed air) is recommended. Wet cleaning (hose or high-pressure spray washer) is prohibited.

The cleaning must always be carried out at low pressure to avoid dust particles getting under the seals.

10.3.2. Greasing

10.3.2.1. Life-lubricated rolling bearings

For motors with **shaft heights SH< 200 mm**, the bearings defined give long grease lifetimes and thus the machines are lubricated for life.

10.3.2.2. Rolling bearings with grease nipple

The bearings are factory-lubricated.

For motors with shaft heights > 225 mm, the bearings are lubricated by grease nipples.

The following table gives the regreasing intervals to be used for an ambient temperature of 25°C for a machine installed with its shaft horizontal, for assemblies with standard bearings and according to the shaft height.

Motors used in ambient temperatures of 40°C must be greased more frequently. The relubrication intervals to be used are approximately 50 % of the values given in the table.

The table in this paragraph is valid for LS open cage motors lubricated with grease (manufacturer's recommendation) ESSO UNIREX N3 use as standard.

The lubrication frequencies and the grease quantity and quality are indicated on the manufacturer's nameplates fixed on the motor. This table can be generalised to all manufacturers.

Motor type Shaft height	**Lubrication interval in hours**			
	3000 RPM160	**1500 RPM**	**1000 RPM**	**750 RPM**
160				
180	Life-lubricated rolling bearings (motors supplied without grease nipples)			
200				
225	7400	15 000	15 000	-
250	5 200	12 600	17 600	-
280	5 200	12 600	17 600	-
315 S/ML/SU/MU	5 800	9 800	15 800	-
315 LD	5 200	9 000	14 400	-
315 MG/LG/VLG	3 400	9 000	18 000	27 000
355	3 400	7 400	16 000	24 000
400	-	4 600	12 000	20 000

Table 18: Lubrication frequency according to motor type

The time interval between two successive greasing operations may depend on additional parameters:

- Environment: motors must be greased more frequently if operated in ambient temperatures of 40°C. The relubrication intervals to be used are approximately 50 % of the values indicated in the table.

- The type of grease if different from ESSO UNIREX N3 (Important: check the compatibilities).

The interval between two greasing operations must never exceed 2 years even after an extended storage or shutdown period.

***Note*:**
In all cases and in particular for special assemblies (motors with a front roller bearing or other assemblies) the maintenance instructions are indicated on the machine manufacturer's nameplate.

Grease type

When the rolling bearings are not life-lubricated, the grease type is indicated on the nameplate.

The standard grease used is ESSO UNIREX N3 and it is recommended (by LS) for later greasing operations.

Do not mix greases.

10.3.2.3. Rolling bearings without grease nipple

Disassemble the motor, remove the old grease and clean the bearings and accessories with degreasing product.

Fill with new grease according to the quantities specified in §6.3.

10.3.2.4. Rolling bearings with grease nipple

LS motor grease nipples are type: TECALEMIT- Hydraulic M8 x 125.

Always begin by cleaning the used grease channel

If the grease indicated on the nameplate is used, remove the covers and clean the grease nipple heads.

Greasing is only fully effective if carried out when the motor is running, this ensures that the new grease is correctly distributed in the bearing

If the greasing cannot be performed with the motor running (basically for safety reasons):

- stop the motor;
- inject only half the quantity of grease specified on the nameplate;
- run the motor for a few minutes;
- inject the remaining half of the grease up to the specified quantity.

Note:

If a different grease is used to that on the nameplate but of equivalent quality, the motor must be disassembled and the bearings and accessories cleaned (carefully clean the grease inlet and outlet ducts) to remove the old grease before regreasing.

Warning:

Too much grease can cause the bearing to overheat **(statistically more bearings are damaged by too much grease than by too little grease).**

Important note:

The new grease must be recently manufactured and must not contain impurities (dust, water, or other).

10.3.3. Checking the bearings

As soon as you detect any of the following on the motor:

- abnormal noise or vibrations,
- bearing overheating although it is correctly lubricated,

the condition of the bearings must be checked.

Damaged bearings must be replaced as soon as possible to prevent greater damage to the motor and driven equipment.

When a bearing must be replaced, **the other bearing must also be replaced**.

The seals must always be replaced when the bearings are replaced.

The non drive end bearing must be installed so that it rotates freely to allow for rotor shaft expansion.

10.4. PREVENTIVE MAINTENANCE

The following table gives the ideal points at which to measure all the parameters which can affect the machine's operation. They must be tested under a test programme to be defined on your site with the maintenance coordinator.

Measurement point	Detector	Type of measurement
1	Accelerometer	Vibration measurements
2	Photoelectric cell	Speed and phase measurements (balancing)
3	Clamp-on ammeters	Current measurements (three-phase and dc)
4	Voltage probe	Voltage measurements
5	Infrared probe	Temperature measurements

Position of measurement points

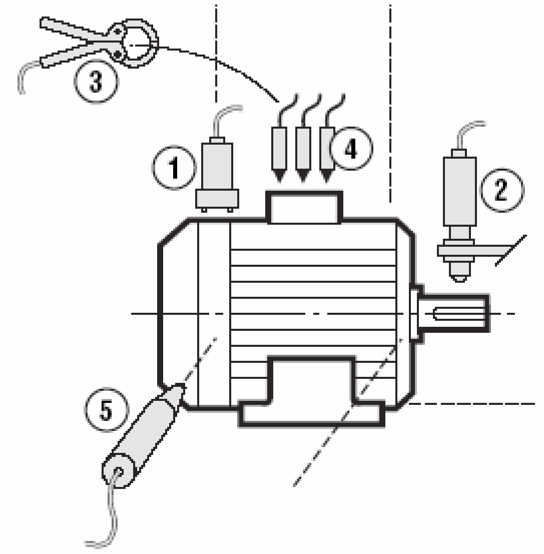


Table 19: Points to be checked for preventive maintenance

10.5. TROUBLESHOOTING GUIDE

Here is a table summarising the typical anomalies which may arise on an electric motor, with the possible causes and proposed solutions.

Incident	Possible cause	Solution
Abnormal noise	Originating in the motor or driven machine?	Uncouple the motor from the driven equipment and test the motor on its own
Motor noisy	**Mechanical cause:** if the noise persists after switching off the electrical power supply	
	- vibrations	- check that the correct key is used for the type of balancing
	- defective bearings	- change the bearings
	- mechanical friction: ventilation, coupling	- check
	Electrical cause: if the noise stops when the electrical power supply is switched off	- check the power supply at the motor terminals
	- normal voltage and 3 phases balanced	- check the terminal strip connections and the tightness of the connectors
	- abnormal voltage	- check the power supply line
	- phase imbalance	- check the resistance of the bearings
Motor overheats	- ventilation problem	- check the environment - clean the fan housing and the motor fins and front grille - check that the fan is correctly fitted on the shaft
	- supply voltage problems	- check
	- wrongly connected terminals	- check
	- overload	- check the current consumption with respect to that indicated on the motor nameplate
	- partial short circuit	- check the electrical continuity of the windings and/or of the installation
	- phase imbalance	- check the resistance of the windings
Motor does not start	**no load** - mechanical seizing - power supply line disconnected or cut	When switched off: - check that the shaft rotates freely by hand - check the fuses, electrical protection, starting device
	on load - phase imbalance	When switched off: - check the rotation direction (phase order) - check the resistance and continuity of the windings - check the electrical protection

Table 20: Typical troubleshooting guide for an electric motor

10.6. CORRECTIVE MAINTENANCE

10.6.1. General

Switch off and lock out the power supply before carrying out any interventions on the motor.

- Open the terminal box, mark the wires and their positions.
- Disconnect the power supply wires.
- Uncouple the motor from the driven equipment.

A puller must be used to extract the components mounted on the end of the motor shaft.

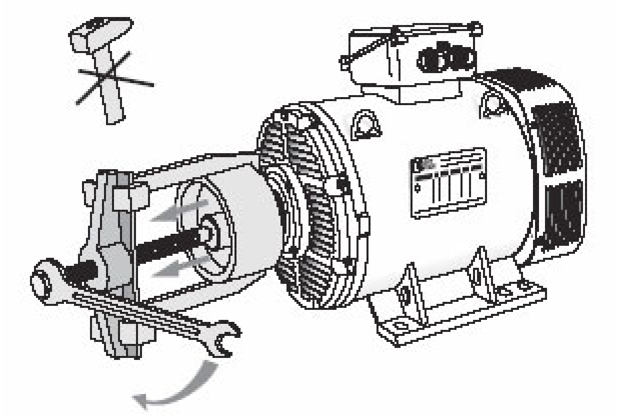


Figure 97: Always use a puller

Disassembling the motor

See the detailed instructions for the relevant motor range).
It is recommended to mark the shields with respect to the stator and the direction the fan is mounted on the rotor.

Before reassembly

Stator:

- remove all dust from the stator:
  If the winding has to be cleaned, a suitable liquid must be used: dielectric and inert with respect to the insulating components and the paintwork,
- check the insulation and, where necessary, dry in an oven,
- clean the spigots thoroughly and remove all traces of impacts on the mating faces if necessary.

Rotor:

- clean and check the bearing seats; if they are damaged, rework the bearing seats or replace the rotor.
- check the condition of the threads, keys and their housings.

Shields, bearings:

- clean off any traces of dirt (old grease, accumulated dust),
- clean the bearing housings and the spigot,
- if necessary, apply antiflash varnish to the insides of the shields,
- carefully clean the bearing retainers and the grease valves.

Mounting the bearings on the shaft

The references of the bearings to be used are indicated on the motor nameplate.

This operation is extremely important as the slightest indentation of a ball on the bearing tracks will cause noise and vibrations.

Lightly lubricate the working surfaces of the shaft.

There are a number of ways of mounting the bearings correctly

- *cold mounting*: the bearings must be mounted without any impacts, using a screw device (do not use a hammer); the insertion force must not be transferred to the bearing track, the internal cage should thus be used for support (take care not to press on the seal shield in the case of sealed bearings).
- *hot mounting*: heat the bearing to between 80 and 100°C: in a dryer, oven or on a heating plate. (Heating with a blowtorch is prohibited in all cases, or heating by oil bath for life-lubricated bearings).

See detailed instructions for the relevant motor range concerned.

Reassembling the motor

Be careful to replace the stator in its original position so that the stack of laminations is centred correctly (generally with the terminal box facing forward) and so that the water drain holes are correctly positioned if they are on the frame.

Tightening the tie rods
The tie rods must be tightened in a diagonal sequence to the specified torque loading. See table with LS reference but which can be applied to all production types

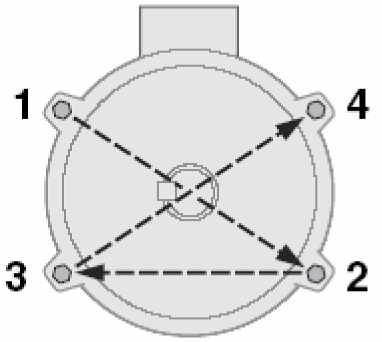


Figure 98: Tightening the motor's tie rods

Tie rod or assembly screw torque loadings		
Type – LS motor reference *The number represents the shaft height*	Rod or screw diameter	Torque loading N.m ± 5%
160 M	M8	18
160 MG/L	M8	18
180 M/L	M8	18
180 LG	M10	25
200 M/LP	M10	25
200 L	M10	25
225 MR	M10	25
250 SP/MP	M12	44
280 SC/MC/MD	M12	44
315 S/SU	M10	25
315 M/MU	M10	25
315 L/LD	M10	25
315 MG/LG	M12	44
315 VLG/VLGU	M12	44
355 L	M12	44
400 L	M10	25

Table 21: Motor shield assembly screw torque loadings

Reassembling the terminal box

Reconnect all the power supply wires as shown in the following diagram or according to the markings made before disassembly.

It is recommended that the motor should be tested with no load

Repaint the motor if necessary.

Mount the transmission device on the output shaft and reinstall the motor on the machine to be driven.

The assembly and reassembly details for LS open motors according to the type (or sizes/powers determined by the shaft heights) are given below. It is perhaps not necessary to give all these operating instruction details but I have decided to include them anyway:

- LS motors are frequently used on our sites
- Assembly instructions are too often rarely available on site, and Internet access is also too much like "Mission: Impossible" for anyone who really needs documents...
- This only represents a few pages
- These instructions can be applied to other manufacturers since the motors are similar

10.6.2. PLS 160 M/MG/L and PLS 180 M/L motors

Disassembly

- remove the screws (27) and then remove the cover (13).
- pull out the fan (7) using a hub puller or, where no hub puller is available, use 2 diametrically opposed levers and use the drive end (DE) shield (6) for support, then remove the fan retaining pin.
- remove the key (21) and withdraw the seals (39 and 54).
- unscrew the tie rods (14) then remove them.
- unscrew the attachment screws (40) from the inner DE bearing retainer (33) in the case of a flanged motor or if there is a locked DE shield, and unscrew screws (62) from the inner non drive end (NDE) bearing retainer (53) in the case of a front roller bearing.
- using a bronze drift, remove the shields (5 and 6) by gently tapping on the shield bosses, recover the preload washer (59).
- remove the circlips (38) if necessary (flanged motor).
- remove the circlips (60) if necessary (motor with roller bearings).
- remove the rotor (3) from the stator (1), on the DE side, taking care not to touch the winding.
- take out the bearings (30) and (50) using a bearing puller while protecting the end of the output shaft with a washer, avoid hitting the running surfaces of the shaft.

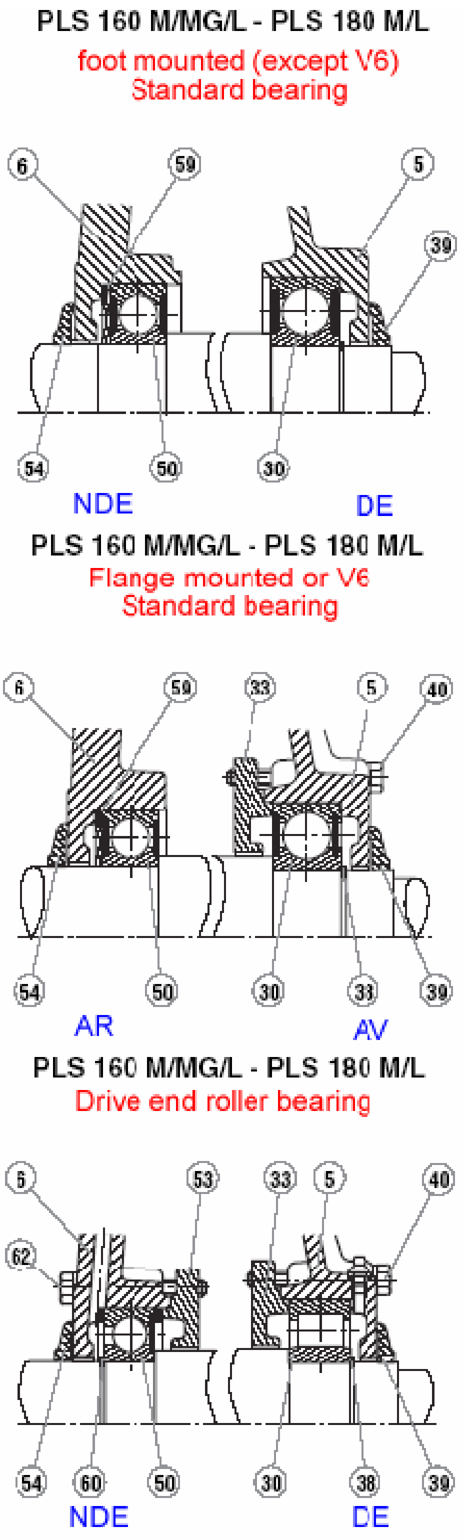
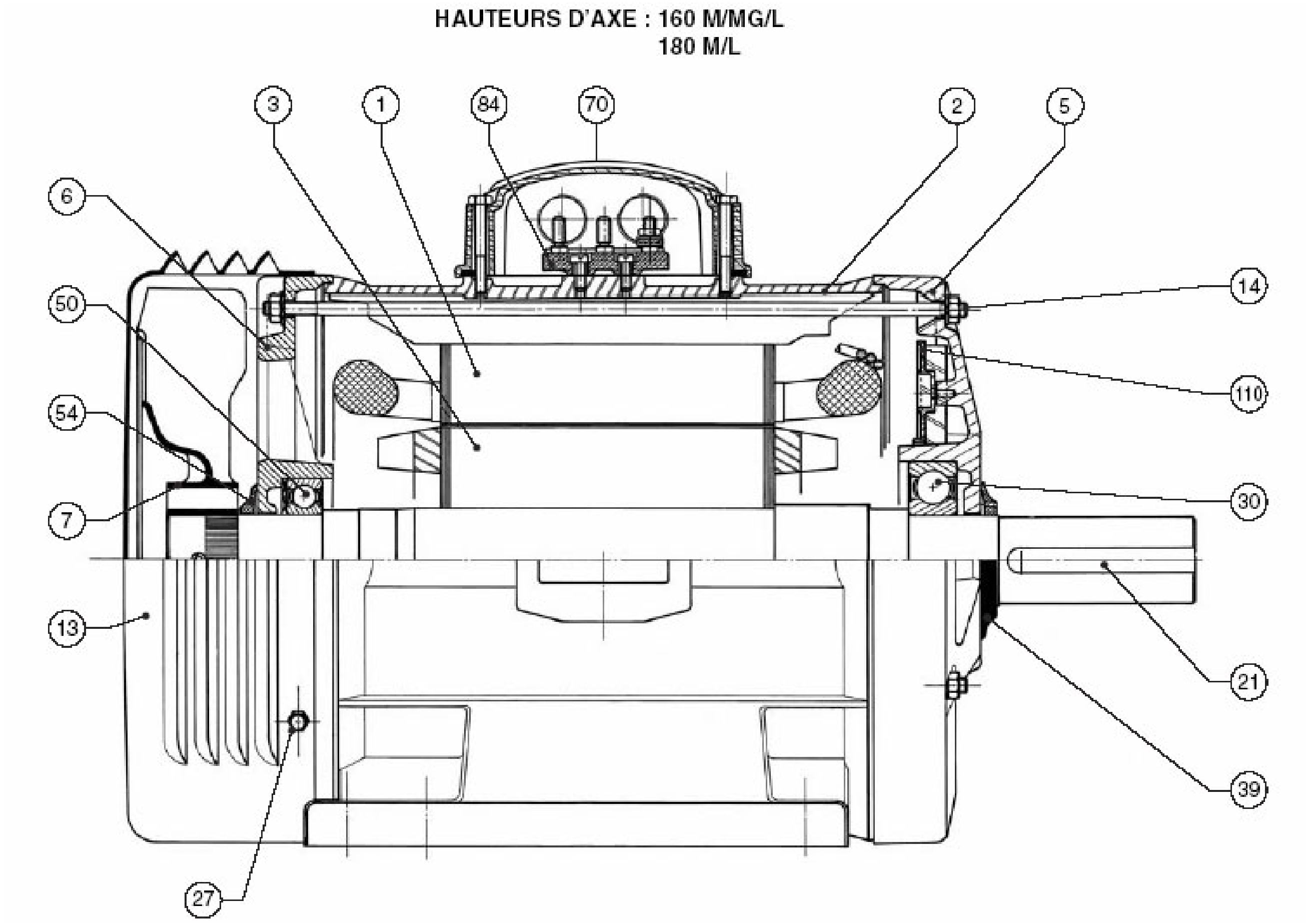


Figure 99: Bearing assembly principle for series 160 and 180 motors

Reassembly

- see the "General" paragraph before reassembly.
- if necessary, insert the inner DE bearing retainer (33) in the rotor drive end and the inner NDE bearing retainer in the non drive end, then fit new bearings on the shaft, see "General" paragraph for the bearing assembly procedure.
- fit the circlips (38) for flanged motors.
- fit the circlips (60) for motors with roller bearings.
- insert the rotor (3) in the stator (1) taking care not to hit the winding.
- if there is a bearing retainer (33), screw a threaded rod with the same thread diameter as the screws (40) into one of the bearing retainer's threaded holes to maintain its angular position when refitting the DE shield (5).
- if there is a bearing retainer (53), screw a threaded rod with the same thread diameter as the screws (62) into one of the bearing retainer's threaded holes to maintain its angular position when refitting the NDE shield (6).
- fit the preload washer (59), with a small amount of grease, in the back of the bearing cage of the NDE shield (6), then refit the NDE shield (6) by positioning it on the stator.
- refit shield (5) taking care to allow for the positioning of the bearing retainer if used.
- insert the tie rods (14) and tighten the nuts in a diagonal sequence up to the recommended torque loading (see § 6.1).
- if necessary, secure the bearing retainer (33) with its screws.
- if necessary, secure the bearing retainer (53) with its screws.
- fit the NDE shield seals (54) with grease and fit the DE shield seals (39).
- fit the fan retaining pin.
- fit the fan (7) using a drift to ensure it is fully home. IMPORTANT: check that it is the right way round!
- check that the rotor rotates freely by hand (ensure that there is no axial play if there is a locked bearing).
- refit the cover (13) and secure it with the screws (27).
- refit the key (21).



1	Wound stator	27	Cover attachment screw
2	Frame	30	Drive end bearing
3	Rotor	39	Drive end seal
5	DE shield	50	Non drive end bearing
6	NDE shield	54	Non drive end seal
7	Fan	59	Preload washer
13	Fan cover	70	Terminal box
14	Tie rods	84	Terminal block
21	Key	110	Protection grille

Figure 100: Details for LS series 160 and 180 motors

10.6.3. PLS 180 LG, PLS 200 M/L/LP and PLS 225 MR motors

Disassembly

- remove the screws (27), the grease nipple (64) and then remove the cover (13).
- pull out the fan (7) using a hub puller or, where no hub puller is available, use 2 diametrically opposed levers and use the DE shield (6) for support, then remove the fan key or retaining pin.
- remove the key (21).
- unscrew the tie rods (14) then remove them.
- unscrew the attachment screws (40) from the inner DE bearing retainer (33), and unscrew screws (62) from the inner NDE bearing retainer (53) and remove them
- using a bronze drift, remove the shields (5 and 6) by gently tapping on the shield bosses, recover the preload washer (59).
- remove the circlips (38) and the circlips (60) if necessary (motor with roller bearings).
- remove the rotor (3) from the stator (1), on the DE side, taking care not to touch the winding with the inner bearing retainer. Take out the bearings (30) and (50) using the bearing puller while protecting the end of the output shaft with a washer, avoid hitting the running surfaces of the shaft.
- the bearings are removed either separately or with the bearing retainers; to avoid damaging the bearing retainers, heat the bearing inner ring to make disassembly easier (the bearing must be discarded).

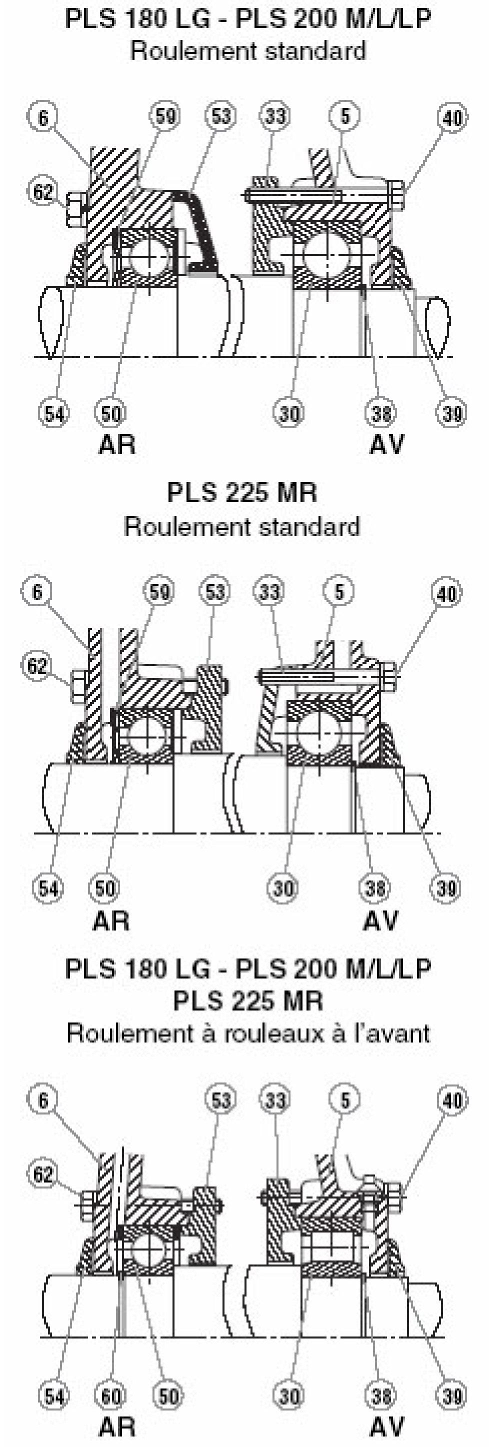
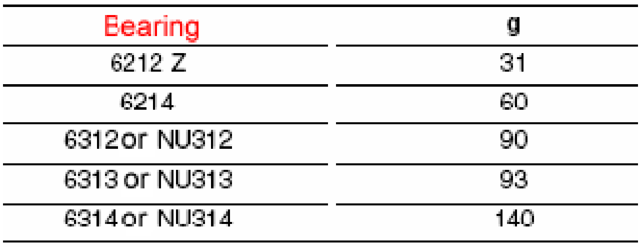


Figure 101: Bearing assembly principle for series 180, 200 and 225 motors

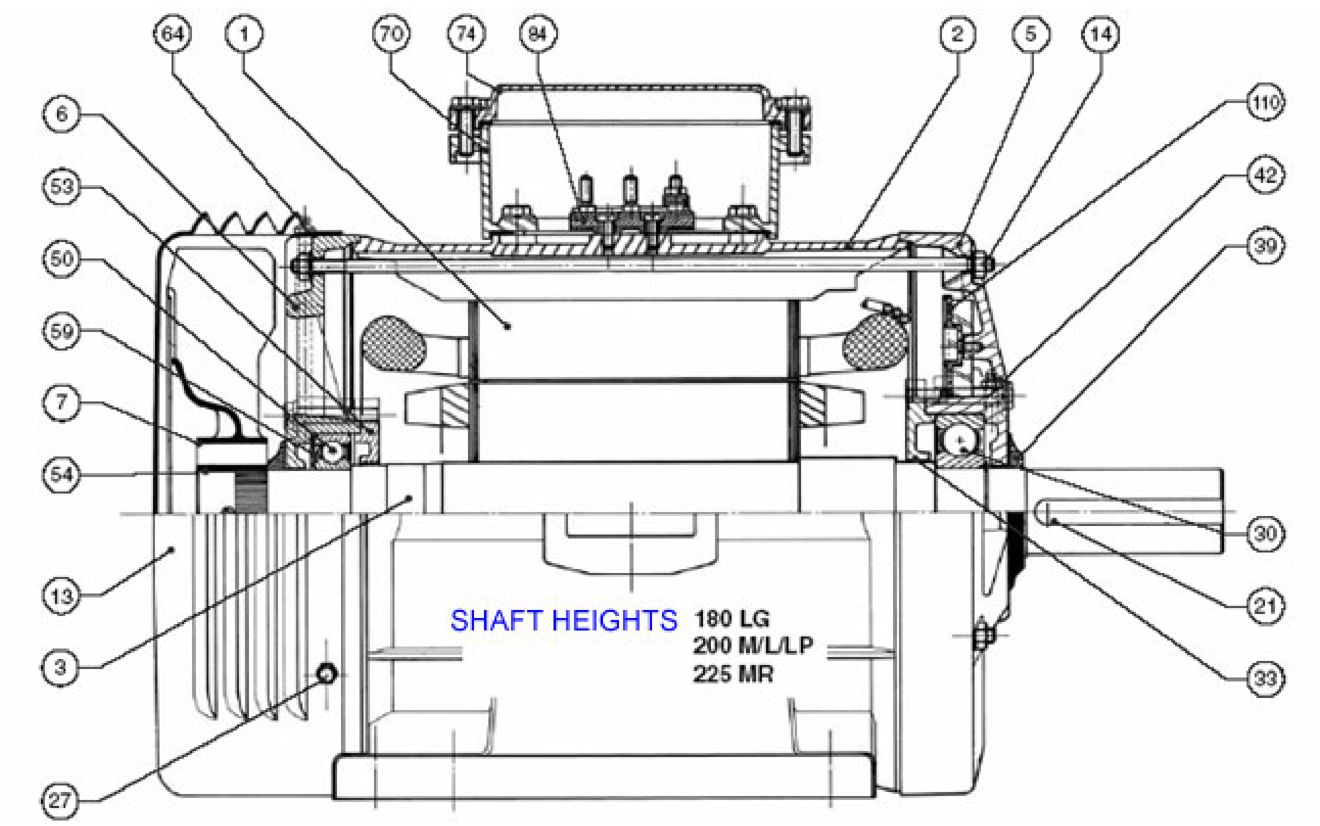
Reassembly

- see the "General" paragraph before reassembly.
- insert the inner DE bearing retainer (33) in the rotor drive end and the inner NDE bearing retainer (53) in the non drive end.
- fit new bearings on the shaft, see "General" paragraph for the bearing assembly procedure.
- insert the rotor (3) in the stator (1) taking care not to hit the winding.
- screw a threaded rod with the same screw diameter as the screws (40) and (62) into one of the threaded holes in the bearing retainers (33) and (53) to maintain the position of the bleed nipple hole when refitting the shields (5 and 6).
- fit the preload washer (59), with a small amount of grease, in the back of the bearing cage of the NDE shield (6), then refit the NDE shield (6) by positioning it on the stator.
- refit shield (5) taking care to allow for the positioning of the bearing retainer (33).
- insert the tie rods (14) and tighten the nuts in a diagonal sequence up to the recommended torque loading (see § 6.1).
- secure the bearing retainer (33) and (53) with its own screws (40) and (62).
- fit the NDE shield seals (54) with grease and fit the DE shield seals (39).
- fit the fan key or retaining pin.
- fit the fan (7) using a drift to ensure it is fully home. IMPORTANT: check that it is the right way round!
- check that the rotor rotates freely by hand (ensure that there is no axial play if there is a locked bearing).
- refit the cover (13) and secure it with the screws (27).
- refit the grease nipple (64).
- use new grease: the quantity is given in the figure in this paragraph. Turn the shaft by hand while applying the grease.
- refit the key (21).



Bearing	g
6212 Z	31
6214	60
6312or NU312	90
6313 or NU313	93
6314or NU314	140

Figure 102: Quantity of grease (in g) according to the type of bearing: series 180, 200 and 225 motors



1	*Wound stator*	39	*Drive end seal*
2	*Frame*	42	*Grease nipple*
3	*Rotor*	50	*Non drive end bearing*
5	*DE shield*	53	*Inner NDE bearing retainer*
6	*NDE shield*	54	*Non drive end seal*
7	*Fan*	59	*Preload washer*
13	*Fan cover*	64	*Grease nipple*
14	*Tie rods*	70	*Terminal box*
21	*Key*	74	*Terminal box lid*
27	*Cover attachment screw*	84	*Terminal block*
30	*Drive end bearing*	110	*Protection grille*
33	*Inner DE bearing retainer*		

Figure 103: Details for LS series 180, 200, 225 motors

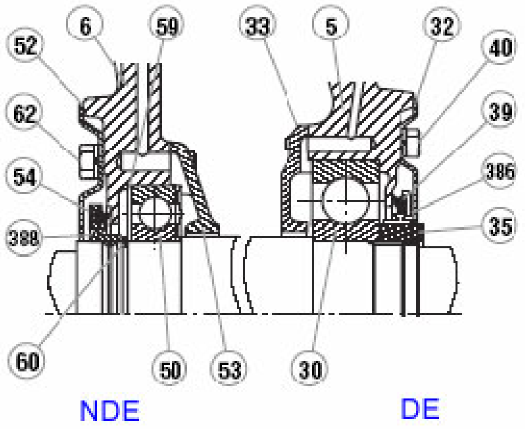
Note concerning the grease quantities given in the figure: *weights valid for ESSO UNIREX N3 grease with perfectly clean grease track + bearing housings + grease evacuation holes).*

10.6.4. PLS 250 and PLS 280 SC/MC/MD motors

Disassembly

- remove the screws (27), the grease nipple (64) and its extension (64) and then remove the cover (13).
- pull out the fan (7) using a hub puller or, where no hub puller is available, use 2 diametrically opposed levers and use the DE shield (6) for support, then remove the fan retaining pin.
- remove the key (21).
- unscrew the tie rods (14) then remove them.
- unscrew the attachment screws (40) from the inner DE bearing retainers (33) and (32) and unscrew the screws (62) from the inner NDE bearing retainers (52) and (53) and remove them.
- unscrew the "Hc" screw of the mobile valve (35) then unscrew the valve using a hook spanner or a tapered bronze drift; unscrew the valve by hand and remove it. The valve maintains the seal (39) and its DE seal support (386) in place.
- using a bronze drift, remove the shields (5 and 6) by gently tapping on the shield bosses, recover the preload washer (59).
- remove the circlips (60).
- remove the rotor (3) from the stator (1), on the DE side, taking care not to touch the winding with the inner bearing retainer.
- take out the bearings (30) and (50) using a bearing puller while protecting the end of the output shaft with a washer, avoid hitting the running surfaces of the shaft.
- the bearings are removed either separately or with the bearing retainers; to avoid damaging the bearing retainers, heat the bearing inner ring to make disassembly easier (the bearing must be discarded).

PLS 250 SP/MP - PLS 280 SC/MC/MD
Standard bearing



PLS 250 - PLS 280
Drive end roller bearings

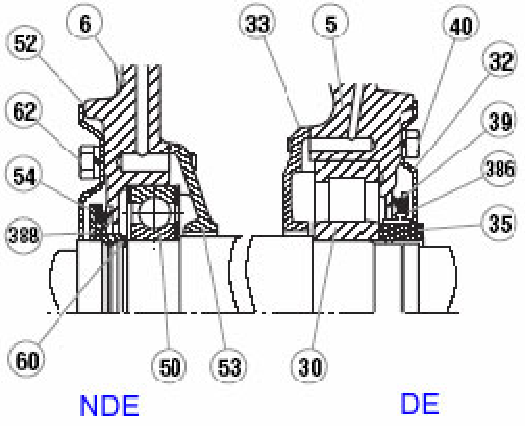
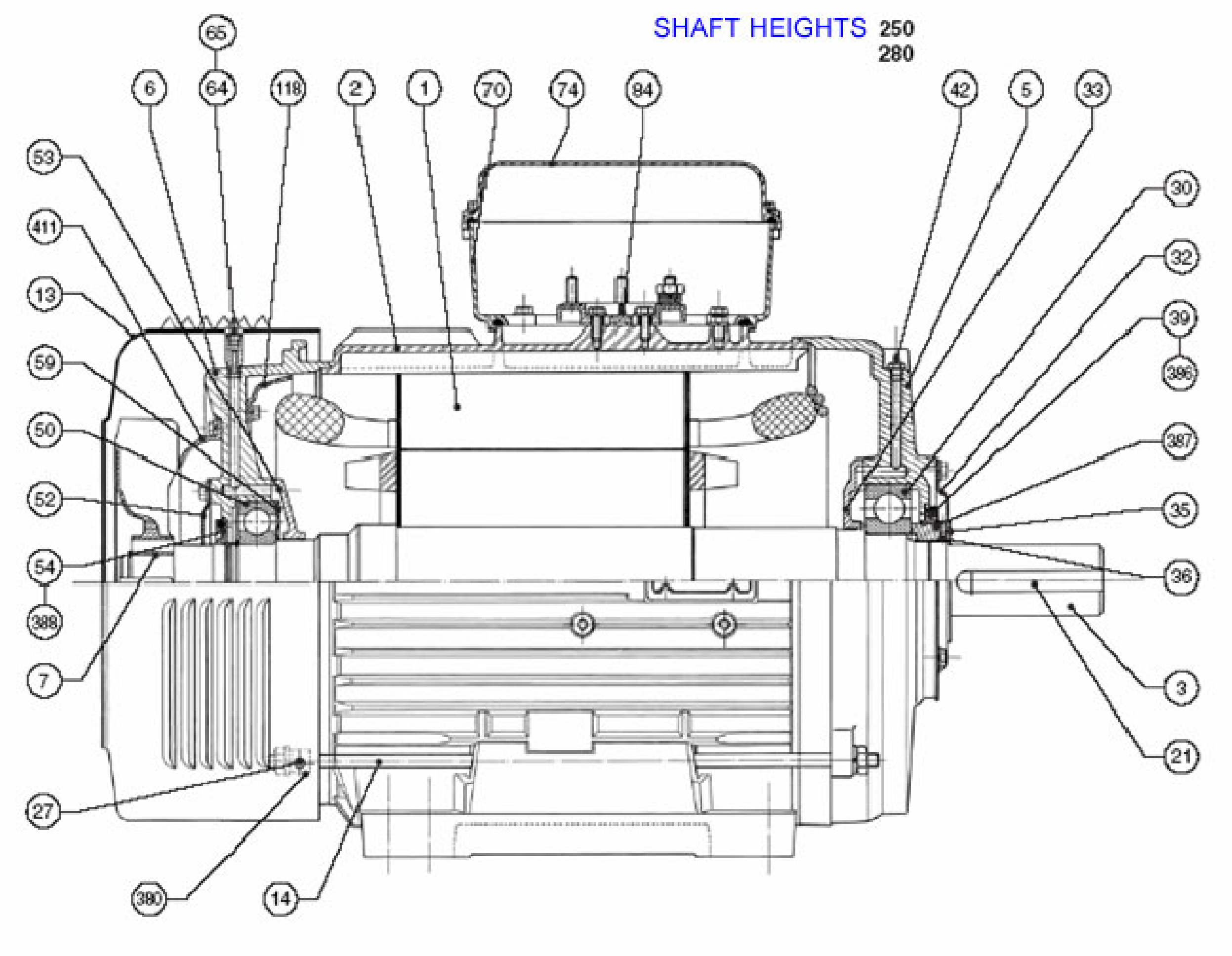


Figure 104: Bearing assembly principle for series 250 and 280 motors



1	*Wound stator*	*50*	*Non drive end bearing*
2	*Frame*	*52*	*Outer NDE bearing retainer*
3	*Rotor*	*53*	*Inner NDE bearing retainer*
5	*DE shield*	*54*	*Non drive end seal*
6	*NDE shield*	*59*	*Preload washer*
7	*Fan*	*64*	*Grease nipple*
13	*Fan cover*	*65*	*NDE grease nipple extension*
14	*Tie rods*	*70*	*Terminal box*
21	*Key*	*74*	*Terminal box lid*
27	*Cover attachment screw*	*84*	*Terminal block*
30	*Drive end bearing*	*118*	*Internal deflector*
32	*Outer DE bearing retainer*	*380*	*Protective cover feet*
33	*Inner DE bearing retainer*	*386*	*DE seal support*
35	*DE mobile grease valve*	*388*	*NDE seal support*
39	*Drive end seal*	*411*	*External deflector*
42	*Grease nipple*		

Figure 105: Details for LS series 250 and 280 motors

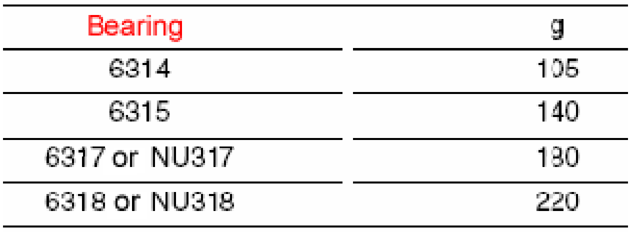
Reassembly

- see the "General" paragraph before reassembly.
- insert the inner DE bearing retainer (33) in the rotor drive end and the inner NDE bearing retainer (53) in the non drive end.
- fit new bearings on the shaft, see "General" paragraph for the bearing assembly procedure.
- refit the circlips (60).
- insert the rotor (3) in the stator (1) taking care not to hit the winding.
- screw a threaded rod with the same screw diameter as the screws (40) and (62) into one of the threaded holes in the bearing retainers (33) and (53) to maintain the position of the bleed nipple hole when refitting the shields (5 and 6).
- fit the preload washer (59), with a small amount of grease, in the back of the bearing cage of the NDE shield (6), then refit the NDE shield (6) by positioning it on the stator.
- on the NDE side, fit the seal (54) and its seal support (388), fit the outer bearing retainer (52) with the locking screws (62) of bearing retainers (52) and (53).
- refit the DE shield (5) taking care to allow for the positioning of the bearing retainer (33).
- fit the mobile valve (35) either by screwing it or locking it, after carefully installing the seal support (386) and its seal (39).
- fit the NDE shield seals (54) with grease and fit the DE shield seals (39).
- fit the outer bearing retainer (32) with the bearing retainer locking screws (40), taking care to ensure that the grease drain hole is at the bottom.
- fit the tie rods (14) without forgetting the feet of the protective cover (380), tighten the nuts in a diagonal sequence without fully tightening them so that the feet of the protective cover can be positioned when it fitted.
- install the fan key.
- fit the fan (7) using a drift to ensure it is fully home or by heating the hub (aluminium fan) to approximately 100°C. IMPORTANT: check that it is the right way round!
- check that the motor rotates freely by hand and that there is no axial play.
- refit the cover (13) and secure it with the screws (27), refit the grease nipple (64) and its extension (65).

- tighten the rod nuts (14) (always tighten in a diagonal sequence), up to the torque loading recommended in the "General" paragraph.

- use new grease: the quantity is given in the figure in this paragraph. Turn the shaft by hand while applying the grease.

- refit the key (21).



Bearing	g
6314	105
6315	140
6317 or NU317	180
6318 or NU318	220

Figure 106: Quantity of grease (in g) according to the type of bearing: series 250 and 280 motors

Same remark as for series 180, 200, 225 motors concerning the quantity of grease and its application.

10.6.5. PLS 315 motors

Disassembly

- remove the screws (27), the grease nipple (64) and its extension (64) and then remove the cover (13)

- pull out the fan (7) using a hub puller or, where no hub puller is available, use 2 diametrically opposed levers and use the DE shield (6) for support; for an aluminium fan heat the hub to approximately 100°C before removing it.

- remove the key (21).

- unscrew the tie rods (14) then remove them.

- unscrew the attachment screws (40) from the inner DE bearing retainers (33) and (32) and unscrew screws (62) from the inner NDE bearing retainers (52) and (53) and remove them.

- unscrew the "Hc" screws of mobile valves (35 and 56) then unscrew the valves using a hook spanner; unscrew the valves by hand and remove them. The valves maintain the supports (386) and (388) of the seals (39 and 54) in place

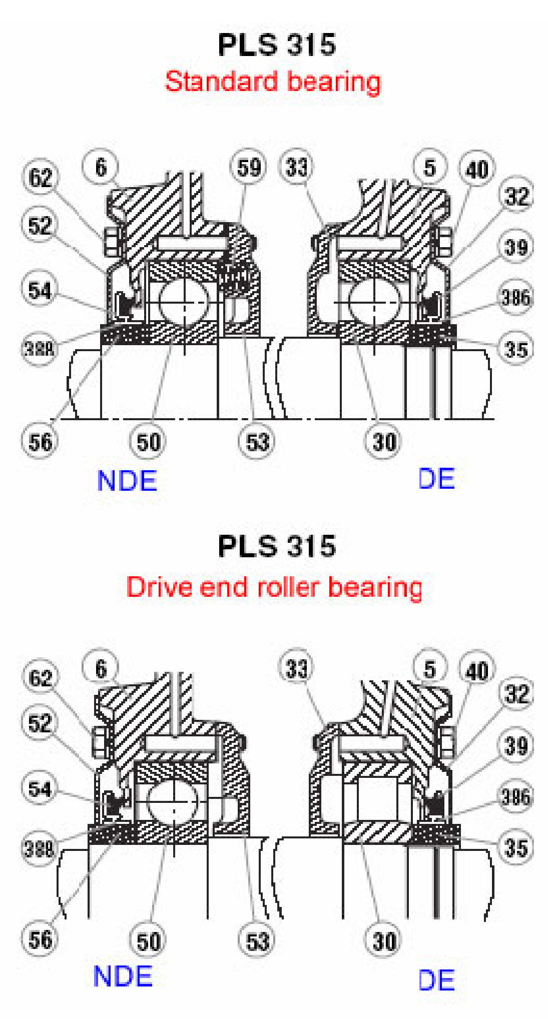


Figure 107: Bearing assembly principle for series 315 motors

- using a bronze drift, remove the shields (5 and 6) by gently tapping on the shield bosses.

- check that the diameter of the bearing retainer (53) is less than that of the stator, otherwise remove the bearing (50) as specified in the following instructions.

- remove the rotor (3) from the stator (1) on the DE side, taking care not to touch the winding with the inner bearing retainer if there is no internal turbine. Remove the bearings (30) and (50) using bearing puller while protecting the end of the output shaft with a washer, avoid hitting the running surfaces of the shaft.

- the bearings are removed either separately or with the bearing retainers (33 and 53); to avoid damaging the bearing retainers, heat the bearing inner ring to make disassembly easier (the bearing must be discarded). - recover the preload washer or springs (59) from the bearing retainer (53).

Reassembly

- insert the inner DE bearing retainer (33) in the rotor drive end and the inner NDE bearing retainer in the non drive end without forgetting to insert the preload springs (59) with a small amount of grease.

- fit new bearings (30 and 50) on the shaft, see "General" paragraph.

- insert the rotor (3) in the stator (1) taking care not to hit the winding.

- screw a threaded rod with the same screw diameter as the screws (40) and (62) into one of the threaded holes in the bearing retainers (33) and (53) to maintain the position of the bleed nipple hole when refitting the shields (5 and 6).

- check that the preload springs are installed.

- fit the NDE shield by positioning it on the stator.

- fit the mobile valve (56) either by screwing it or locking it, after carefully installing the seal support (388) and its seal (54).

- fit the outer bearing retainer (52) with the bearing retainer locking screws (62), taking care to ensure that the grease drain hole is at the bottom.

- fit the DE shield (5) by positioning it on the stator.

- fit the mobile valve (35) either by screwing it or locking it, after carefully installing the seal support (386) and its seal (39).

- fit the NDE shield seals (54) with grease and fit the DE shield seals (39).

- fit the outer bearing retainer (32) with the bearing retainer locking screws (40), taking care to ensure that the grease drain hole is at the bottom.

- fit the tie rods (14) without forgetting the feet of the protective cover (380), tighten the nuts in a diagonal sequence without fully tightening them so that the feet of the protective cover can be positioned when it fitted.

- install the fan key.

- fit the fan (7) using a drift to ensure it is fully home or by heating the hub (aluminium fan) to approximately 100°C. IMPORTANT: check that it is the right way round!

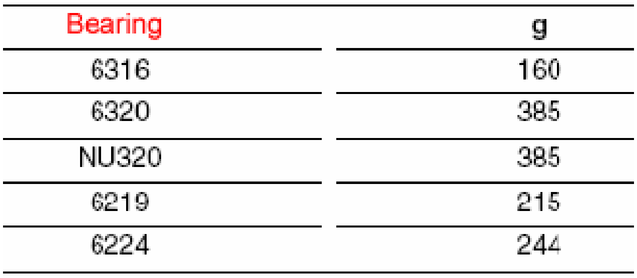
- check that the motor rotates freely by hand and that there is no axial play.

- refit the cover (13) and secure it with the screws (27), refit the grease nipple (64) and its extension (65).

- use new grease: the quantity is given in the figure in this paragraph. Turn the shaft by hand while applying the grease.

- tighten the rod nuts (14) (always tighten in a diagonal sequence), up to the torque loading recommended in the "General" paragraph.

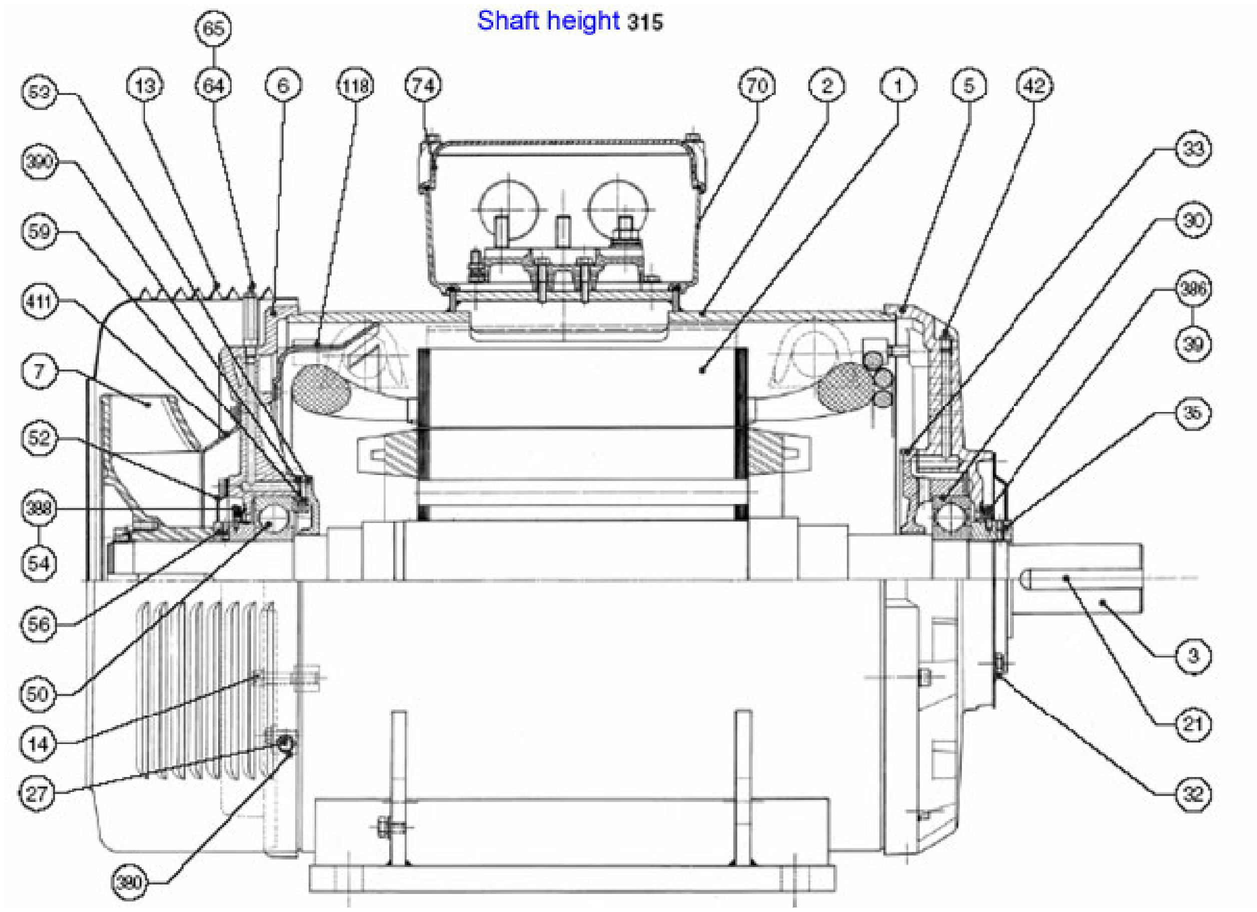
- refit the key (21).



Bearing	g
6316	160
6320	385
NU320	385
6219	215
6224	244

Figure 108: Quantity of grease (in g) according to the type of bearing: series 315 motor

Same remark as for series 180, 200, 225 motors concerning the quantity of grease and its application.



1	Wound stator	52	Outer NDE bearing retainer
2	Frame	53	Inner NDE bearing retainer
3	Rotor	54	Non drive end seal
5	DE shield	56	NDE mobile grease valve
6	NDE shield	59	Preload washer
7	Fan	64	Grease nipple
13	Fan cover	65	NDE grease nipple extension
14	Tie rods	70	Terminal box
21	Key	74	Terminal box lid
27	Cover attachment screw	84	Terminal block
30	Drive end bearing	118	Internal deflector
32	Outer DE bearing retainer	380	Protective cover feet
33	Inner DE bearing retainer	386	DE seal support
35	DE mobile grease valve	388	NDE seal support
39	Drive end seal	390	Internal NDE bearing retainer spacer
42	Grease nipple	411	External deflector
50	Non drive end bearing		

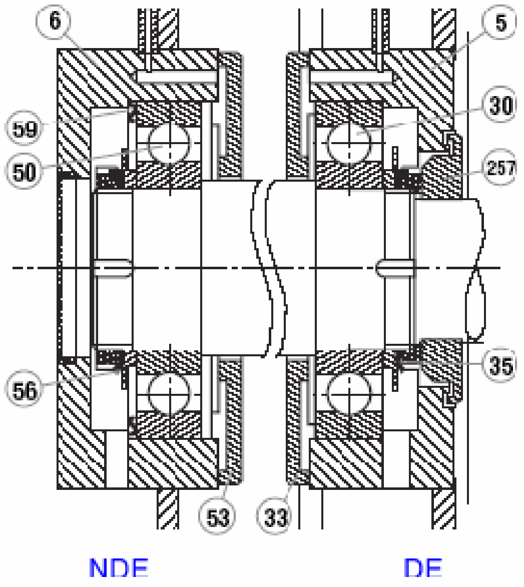
Figure 109: Details for LS series 315 motors

10.6.6. PLS 355 and PLS 400 motors

Disassembly

- remove the screws and then remove the straps from the shields (114).
- remove the key from the output shaft (21).
- unscrew the DE and NDE shield (5 and 6) screws.
- unscrew the attachment screws from the inner bearing retainers (33 and 53).
- unscrew the labyrinth seal (257) attachment screws and remove it. If necessary, heat it slightly using a flame.
- using a bronze drift and a hoist to relieve the weight on the assembly, remove shields (5) and (6), and recover the washers (59) or preload springs, depending on the configuration.
  Note: on some shields there are threaded holes to make it easier to remove them using screws.
  If the motors are equipped with bearing probes, disconnect the probes at the terminal box before removing the shields and push the cables into the motors, then pull on the cables as the bearing is withdrawn.
- bend back the tabs on the DE and NDE nut tabwashers and unscrew the nuts.

PLS 355 - PLS 400
Standard bearing



PLS 355 - PLS 400
Drive end roller bearing

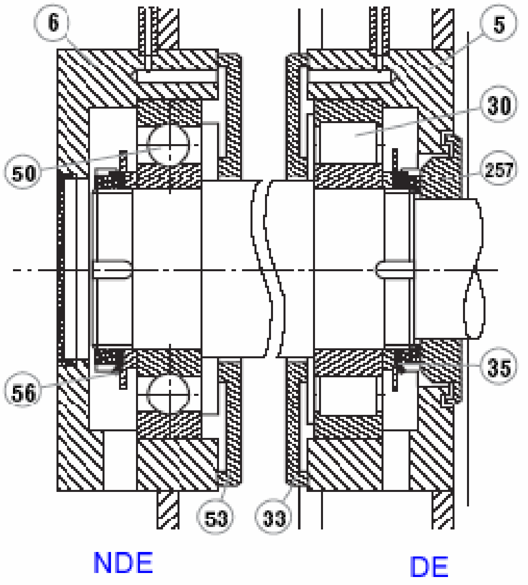


Figure 110: Bearing assembly principle for series 355 and 400 motors

- remove the deflectors from the DE and NDE grease valves (35) (56).
- remove the bearings using a bearing puller, either on their own or with their inner bearing retainers (33) (53). To avoid distorting the bearing retainers heat the bearing inner ring using a flame (the bearing must be discarded).
- withdraw the rotor with its fan from the non drive end of the stator taking care not to touch the winding.

- to disassemble the fan (7) (if necessary): after bending back the tabs on the nut tabwasher and unscrewing the nut, heat the fan hub with a flame and remove it either manually or using threaded rods in the threaded holes on the hub.

Reassembly

- heat the fan (7) and refit it on the shaft, then fit the nut with its tabwasher, tighten them and lock with the locking tabs.
- Rebalance the rotor and fan assembly (3) (7) if a new fan is being installed.

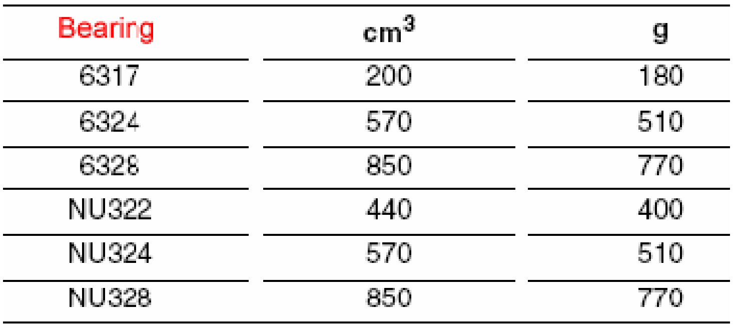
- insert the rotor in the stator, take care not to touch the winding.

- refit the inner bearing retainers (33) (53).

- refit the new bearings (30) (50) (heated to 100-110° by: a bearing heater, oven or oil bath).

- fit the deflectors (35) (56) then the nuts with their tabwashers, tighten them and lock with the locking tabs.

- grease the bearings as specified in the following table:



Bearing	cm^3	g
6317	200	180
6324	570	510
6328	850	770
NU322	440	400
NU324	570	510
NU328	850	770

Figure 111: Quantity of grease (in g) according to the type of bearing: series 355 and 400 motors

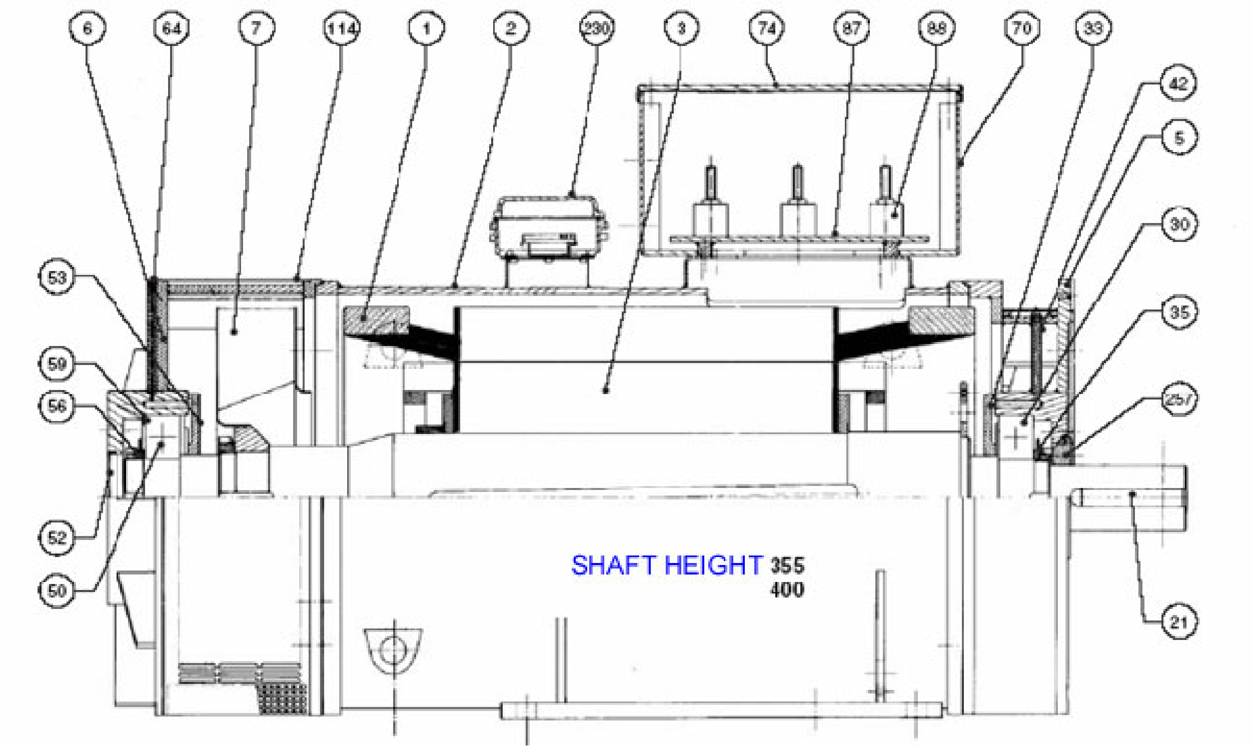
Same remark as for series 180, 200, 225 motors concerning the quality and quantity of grease, and its application.

- before refitting the shields (5) (6), screw a threaded rod into one of the threaded holes in the inner bearing retainers (33) (53) to ensure that the lubrication hole is correctly positioned.
- if the motors are equipped with bearing sensors, use a needle-type tool to guide the cables into the terminal box. Refit the shields with the preload washers or springs (59) held with a little grease. Screw up the screws of the shields and inner bearing retainers (33) (53).

- refit the labyrinth seal (257), lock it and check that the rotor rotates freely.

- refit the strap(s) (114) on the shields (5) (6).

- refit the key (21).



1	*Wound stator*	*52*	*Outer NDE bearing retainer*
2	*Frame*	*53*	*Inner NDE bearing retainer*
3	*Rotor*	*56*	*Mobile part of NDE grease valve*
5	*DE shield*	*59*	*Preload washer*
6	*NDE shield*	*64*	*NDE grease nipple*
7	*Fan*	*70*	*Terminal box*
21	*Key*	*74*	*Terminal box lid*
30	*Drive end bearing*	*87*	*Insulator support*
33	*Inner DE bearing retainer*	*88*	*Insulators*
35	*DE mobile grease valve*	*114*	*NDE bearing strap*
42	*DE grease nipple*	*230*	*Cast iron terminal box for built-in thermal protections*
50	*Non drive end bearing*	*257*	*Labyrinth seal*

Figure 112: Details for LS series 355 and 400 motors

10.7. INSULATION VALUES

10.7.1. Insulation measurement and scheduled maintenance

The typical insulation values are given for measurements taken on new motors, factory values or commissioning values.

Once on site, and after many years or at least after many hours of service, our motors are still operational but the insulation values are far from the initial "ideal" values.

The following table summarises the insulation values, between phase and earth, according to the operating voltages. These values are based on experience giving "reasonable" measurement values when we know the operating and environment conditions of our motors…

INSULATION (MΩ)	Bad	Insufficient	Acceptable	Good
24 Volts	< 1 KΩ	1 KΩ to 25 KΩ	25 KΩ to 50 KΩ	> 50 KΩ
50 Volts	< 1 KΩ	1 KΩ to 50 KΩ	50 KΩ to 100 KΩ	> 100 KΩ
220 Volts	< 1 KΩ	1 KΩ to 250 KΩ	250 KΩ to 500 KΩ	> 500 KΩ
380 Volts	< 1 KΩ	1 KΩ to 400 KΩ	400 KΩ to 800 KΩ	> 800 KΩ
660 Volts	< 1 KΩ	1 KΩ to 700 KΩ	700 KΩ to 1400 KΩ	> 1400 KΩ
5000 Volts	< 1 KΩ	1 KΩ to 5 MΩ	5 MW to 10 MΩ	> 10 MΩ
20000 Volts	< 1 KΩ	1 KΩ to 20 MΩ	20 MW to 40 MΩ	> 40 MΩ

Table 22: Insulation acceptability experience values for the motors on site

10.7.2. Effect of climatic conditions

Two environment parameters have a considerable effect on insulation measurements: temperature and humidity level

10.7.2.1. Temperature

The temperature varies the insulation resistance value according to an almost exponential law. In the context of a maintenance programme for a fleet of motors, it is therefore important to take regular measurements in similar temperature conditions. Otherwise the results will have to be corrected to convert them to a fixed reference temperature.

As an example, the IEEE 43 standard for rotating machines gives, as an approximation, dividing the insulation by 2 for each 10°C increase (and vice versa). The graph shown opposite can serve as the basis for this correction.

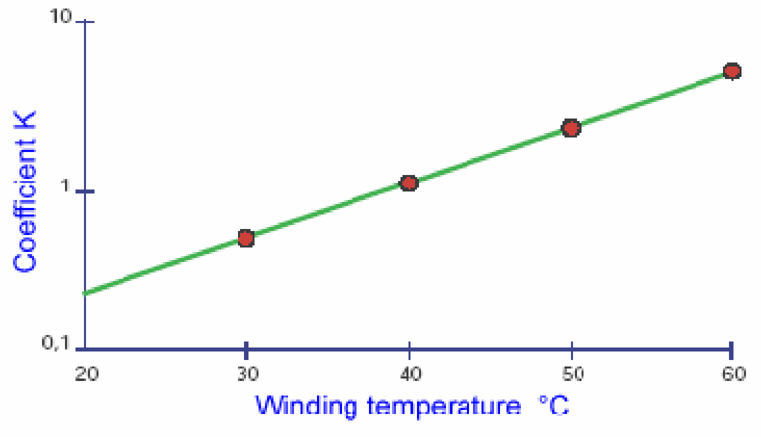


Figure 113: Insulation resistance according to temperature

10.7.2.2. Humidity level

The humidity level affects the insulation according to the level of contamination of the insulating surfaces. We must always ensure that measurements are never carried out if the temperature is less than the dew point temperature.

Monitoring these two parameters, temperature and humidity, during insulation measurements allows reliable and comparable results to be obtained, and therefore a good quality predictive maintenance which optimises the operating life of electrical equipment.

10.7.3. Interpreting insulation measurements

Interpretation is a fundamental element in all measurement. Measuring the insulation value readings from time to time can give random results if, for humidity conditions which are taken to be fixed, the effect of the temperature is not corrected.

The aim of the two methods described below is to simplify the interpretation of the measurements and to detect insulation deterioration by observations over time.

10.7.3.1. Method based on the effect of the test voltage application time (Polarisation index)

This method has the advantage of being little affected by the temperature (thanks to the "comparative" principle) which makes it easily applicable without having to correct the results. It is particularly well-adapted to predictive maintenance for rotating machines and to monitoring the ageing of their insulations.

To do this, here is a reminder of the different currents flowing when measuring an insulation resistance (see graph).

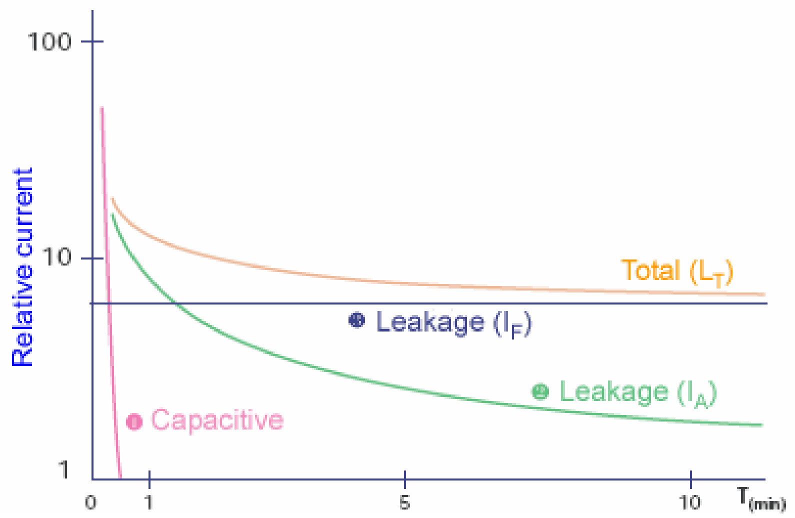


Figure 114: Curves of the current components during an insulation test

Capacitive curve **(Ic)**: it corresponds to the tested circuit's capacitive component charging current. This transient current falls rapidly after a few seconds, or even after a few tens of seconds, and becomes negligible with respect to the leakage current IL to be measured.

Absorption current curve (I_A): dielectric absorption current decreases much more slowly. In particular, it provides the energy necessary for the insulation molecules to line up according to the electrical field applied.

Leakage current curve **(I_L)**: this is the leakage current characteristic of the insulating resistance.

Total Curve **(I_T) =** (I_A) + **(I_L)** *(logarithmic scale, the y-axis on the graph)*

There are two possible cases if the test voltage is applied for a long time:

a) The insulation is excellent (insulation in good condition, clean and dry).

In this case the leakage current is very low and the measurement is greatly influenced by the capacitive load currents and the dielectric absorption current. The insulation resistance measurement will therefore increase during the time the test voltage is applied since these spurious currents are decreasing.

The length of time required for the measurement to stabilise depends on the type of insulations. With the old types of insulation, a stable value is normally reached after 10 or 15 minutes. With some recent types of insulations (e.g. epoxy mica or polyester mica) the measurement can stabilise after approximately 2 to 3 minutes.

b) The insulation is bad (insulation deteriorated, dirty and damp).

The leakage current is very high (and constant) and outclasses the capacitive load current and dielectric absorption current. In this case the insulation resistance measurement will very quickly reach a constant and stable level.

From an examination of the curves for the insulation variation according to the test voltage application time (figure "Typical insulation resistance variations according to measurement time"), it is possible to complete the "absolute" insulation measurement by ratios expressing the good or bad condition of the insulations.

For example, we calculate the ***quotient*** of the insulation resistance value read after the test voltage has been applied for ***10 minutes***, over the value read after ***one minute*** of application.

We obtain a quotient called the ***"Polarisation Index (PI)".*** However, this index alone is not sufficient. It only completes the absolute insulation values provided in the standards or defined by the rotating machine manufacturers.

PI = R$_{\text{insulation}}$ **after 10 minutes / R**$_{\text{insulation}}$ **after 1 minute**

- If PI < 1 the insulation is dangerous
- If PI < 2 the insulation is doubtful
- If PI < 4 the insulation is good
- If PI > 4 the insulation excellent

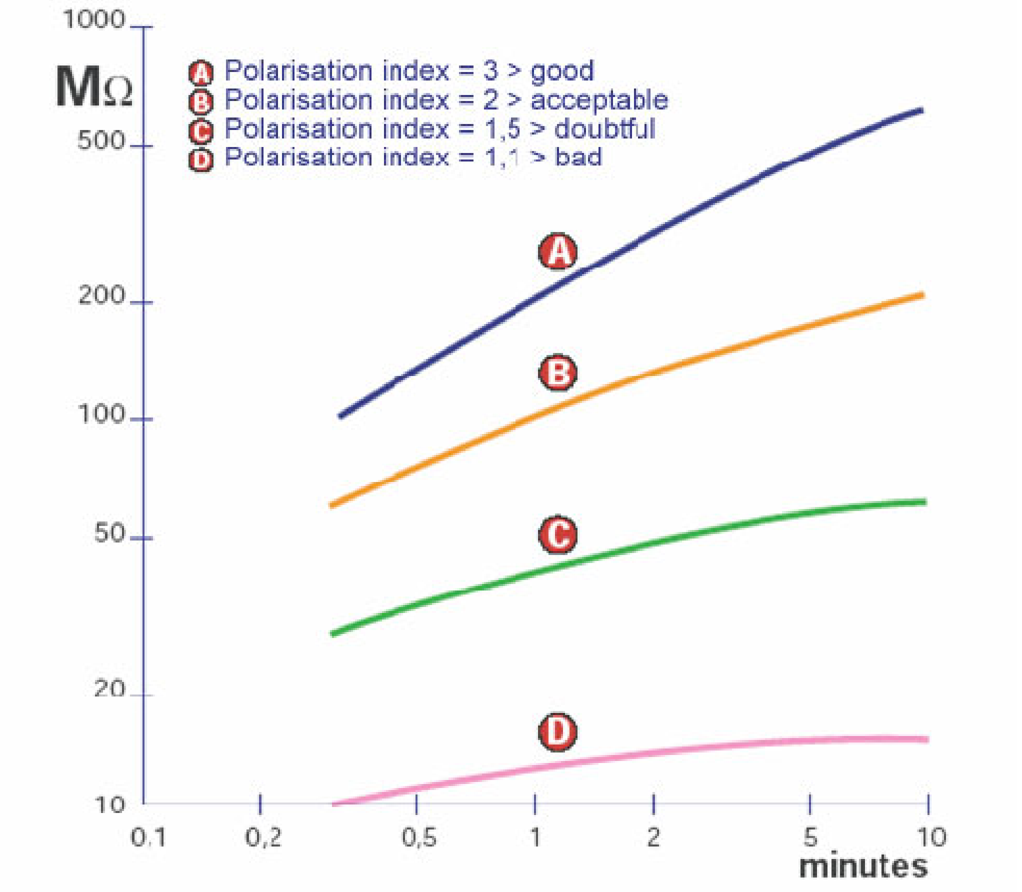


Figure 115: Typical insulation resistance variations according to measurement time

As described previously, the most recent insulations have a dielectric absorption current which decreases more quickly than with the old insulations. Therefore, the measurement sometimes stabilises after 2 to 3 minutes.

The ***“Dielectric Absorption Ratio (DAR)”,*** which is the ***coefficient*** of the values after ***1 minute and 30 seconds***, may thus be sufficient to qualify certain recent insulations as "Good".

DAR = $R_{insulation}$ after 1 minute / $R_{insulation}$ after 30 seconds

- If DAR < 1.25 the insulation is insufficient
- If DAR < 1.6 the insulation is good
- If DAR > 1.6 the insulation is excellent

The change in the PI or DAR coefficients over time can therefore greatly simplify predictive the maintenance of a fleet of machines, for example.

Important: IP also stands for Protection Index, which also applies to a motor.

10.7.3.2. Method based on the effect of test voltage variation (stepped measurement)

The presence of contaminants (dust, dirt, etc.) or humidity on the surface of the insulations is generally well-detected by the measurements based on test voltage application time (DAR, PI, etc). However, insulation ageing or some types of mechanical damage can sometimes escape detection by this type of test carried out at a low voltage with respect to the dielectric voltage of the insulation tested.

However, a significant increase in the test voltage applied can cause these weak spots to break, which will result in a sharp reduction in the insulation value measured.

For this method to be effective, we normally decide to apply a series of steps at a sufficient voltage, with a ratio of 5 to 1, in one or more equivalent time steps (e.g. 1 minute), while remaining well below the traditional dielectric test voltage (2 Un + 1000 V).

This method gives results which are totally independent of the type of insulation and the temperature because we do not use the intrinsic value of the insulations measured but the effective reduction in the value read after an identical time, at two different test voltages. A reduction of 25% or more in the insulation resistance between the first and second levels is a sign that the insulation has deteriorated.

11. GLOSSARY

12. SOMMAIRE DES FIGURES

Figure 1: Basic Electrical Components of an AC Motor 7
Figure 2: Stators of induction motor 7
Figure 3: Rotors of induction motor 8
Figure 4: Stator and rotor 8
Figure 5: Connecting 3 Ph motor in mono 9
Figure 6: Pilot motor method 10
Figure 7: Typical three phase motor (squirrel cage) 11
Figure 8: Details of construction for a typical three phase motor 13
Figure 9: Typical rotor construction (squirrel cage) 15
Figure 10: Typical rotor construction (squirrel cage and lamination) 15
Figure 11: Typical squirrel cage motor 17
Figure 12: Typical Motor Nameplate 18
Figure 13: Correction factor for power with different Temperature and Altitude conditions 24
Figure 14: Correction factor for power as per % of Voltage unbalanced 31
Figure 15: Example (minimum) of a nameplate 33
Figure 16: Example (complete) of a nameplate 34
Figure 17: Squirrel cage Rotors 36
Figure 18: Typical Bearing 36
Figure 19: Endshields or Endbells (flasques) of a motor 36
Figure 20: Insulation of bearings 37
Figure 21: Motor with Air-Air exchanger 45
Figure 22: Open motor with or without filter 45
Figure 23: Motor with Air pulse cooler 45
Figure 24: Motor with Air-Water exchanger 46
Figure 25: Connection directly on 3 terminal in the connection box 47
Figure 26: Four Terminal Connections – Dual Voltage Motor 48
Figure 27: The basic six terminal connections 48
Figure 28: Typical starting curves of an induction motor (squirrel cage) 50
Figure 29: Example of Motor Reversal 52
Figure 30: Isolation device - Isolator 55
Figure 31: Short-circuit Protection by fuses 55
Figure 32: Power snitching device – the Contactor 56
Figure 33: Protection by Thermal Overload 56
Figure 34: Typical motor starter protection (old system) 57
Figure 35: The motor-breaker protection system (overload thermal and magnetic) 58
Figure 36: Centrifugal switch 60
Figure 37: Casing heating system 61
Figure 38: DC supply for winding / motor heating 61
Figure 39: The basic starting curve and the protections 62
Figure 40: The basic protection curve for motor start protection 63
Figure 41: Adjustable thermal and magnetic trip unit on a breaker 64
Figure 42: Typical protection types on induction motor starting curve 67
Figure 43: Independent time protection 69
Figure 44: Dependent time protection 70
Figure 45: Curves inverse, very inverse and extremely inverse with T = 1 s 70

Figure 46: Basic design of a magnetic relay 71
Figure 47: Measure of the residual current by a torus 72
Figure 48: Measure of the residual current with three current transformers....................73
Figure 49: Inrush current of the motor with its associated starting system....................73
Figure 50: Case of a rotor locking....................74
Figure 51: Case of no-load motor 75
Figure 52: Typical Direct On Line motor Starter....................77
Figure 53: Direct start protection by motor-breaker 78
Figure 54: Direct motor start with by-pass of thermal relay – power circuit....................79
Figure 55: Direct motor start with by-pass of thermal relay – control circuit....................79
Figure 56: Direct start – two rotations directions – power circuit....................80
Figure 57: Direct start – two rotations directions – control circuit....................81
Figure 58: Dahlander delta/wye coupling (constant torque)....................82
Figure 59: Dahlander wye/wye-wye coupling (quadratic torque) 83
Figure 60: Direct start – two speed – two rotation directions – Dahlander coupling – power circuit 84
Figure 61: Direct start – two speed – two rotation directions – Dahlander coupling – control circuit 85
Figure 62: Differences between delta and star connections 87
Figure 63: Starter “Star-Delta – power circuit....................90
Figure 64: Starter “Star-Delta – control circuit solution 1 91
Figure 65: Starter “Star-Delta – control circuit solution 2 92
Figure 66: Starter “Star-Delta + reverse rotation – power circuit....................93
Figure 67: Starter “Star-Delta + reverse rotation – control circuit – reverse after action on “0” 93
Figure 68: Starter “Star-Delta + reverse rotation – control circuit – reverse without action on “0” 94
Figure 69: Motor fault – Shorts between windings....................95
Figure 70: Motor fault – Shorts inside a winding....................95
Figure 71: Motor fault – Open winding....................95
Figure 72: Motor fault – Insulation break in winding....................95
Figure 73: Motor Plugging system – Power circuit diagram....................99
Figure 74: Motor Plugging system – Control circuit diagram with speed switch....................99
Figure 75: Motor Plugging system – Control circuit diagram with time delay relay 100
Figure 76: Scheme of a D.C. injection system for A.C. motor braking....................103
Figure 77: Using a “Growler” to test for shorted coil 106
Figure 78: Example of Growler units – Bench type - Martindale....................107
Figure 79: Example of Growler units – Portable type - Martindale....................107
Figure 80: Use of a Growler (Martindale type F) to test a DC rotor....................108
Figure 81: Typical manufacturer's nameplate....................110
Figure 82: Insulation measurement before entry into service 113
Figure 83: Motor cooling / ventilation....................114
Figure 84: Installation of an electric motor....................114
Figure 85: Turn the motor by hand 115
Figure 86: Rotor lock 115
Figure 87: Installing the coupling 117
Figure 88: Coupling fully in contact on the shoulder of the shaft....................117
Figure 89: Adjusting the parallelism....................118

Figure 90: Tolerances with rigid sleeve coupling 119
Figure 91: Fitting the belts 119
Figure 92: Alignment of the pulleys...120
Figure 93: Adjusting the slide rails 120
Figure 94: Connection to the terminal box 123
Figure 95: Graph for choosing power supply cable cross-sectional area with a max. voltage drop of 3%...124
Figure 96: Connecting to the terminals 125
Figure 97: Always use a puller...132
Figure 98: Tightening the motor's tie rods...133
Figure 99: Bearing assembly principle for series 160 and 180 motors 135
Figure 100: Details for LS series 160 and 180 motors 137
Figure 101: Bearing assembly principle for series 180, 200 and 225 motors 138
Figure 102: Quantity of grease (in g) according to the type of bearing: series 180, 200 and 225 motors...139
Figure 103: Details for LS series 180, 200, 225 motors 140
Figure 104: Bearing assembly principle for series 250 and 280 motors 141
Figure 105: Details for LS series 250 and 280 motors 142
Figure 106: Quantity of grease (in g) according to the type of bearing: series 250 and 280 motors...144
Figure 107: Bearing assembly principle for series 315 motors 144
Figure 108: Quantity of grease (in g) according to the type of bearing: series 315 motor146
Figure 109: Details for LS series 315 motors...147
Figure 110: Bearing assembly principle for series 355 and 400 motors 148
Figure 111: Quantity of grease (in g) according to the type of bearing: series 355 and 400 motors...149
Figure 112: Details for LS series 355 and 400 motors 150
Figure 113: Insulation resistance according to temperature 152
Figure 114: Curves of the current components during an insulation test 153
Figure 115: Typical insulation resistance variations according to measurement time......154

13. SOMMAIRE DES TABLES

Table 1: Frame construction and fixation codification for motors 22
Table 2: The Service factor / type classification for an electric motor 29
Table 3: Unbalance of phases Voltage for motor supply 30
Table 4: Class of Insulation for windings of rotating machines 38
Table 5: Numbering codes system for cooling of rotating machines.................................40
Table 6: lettering codes system for cooling of rotating machines......................................41
Table 7: Examples of cooling coding – simplified system 43
Table 8: Examples of cooling coding – complete system 44
Table 9: Different categories for contactors 59
Table 10: Typical fault detections of a multi-functions relay for a motor 65
Table 11: Different thermal protection possibilities with a Star-Delta starter......................89
Table 12 :LV Motors types of electrical faults and testing methods 96
Table 13: DC motor - Brush commutator maintenance...108
Table 14: Definition of symbols used on nameplates..111
Table 15: Use of greases and bearings according to the storage period.........................112
Table 16: Power limit for connection to the mains electricity supply 121
Table 17: Terminal nut torque loadings 125
Table 18: Lubrication frequency according to motor type 127
Table 19: Points to be checked for preventive maintenance...130
Table 20: Typical troubleshooting guide for an electric motor...131
Table 21: Motor shield assembly screw torque loadings...134
Table 22: Insulation acceptability experience values for the motors on site....................151